AUTO TECH

AUTO-TECH MASTERCLASS

Training for Master Technicians

2020.1

CRD BEYOND 2020

What does the future
hold for CRD

FUEL INJECTOR DIAGNOSTIC TECHNIQUES

- Scan tool data
- Back leakage quantity
- Back leakage pressure
- Fuel rail pressure analysis
- Injection pressure ripples

DIESEL NO START DIAGNOSIS

Requirements and procedures

CRD INJECTOR DIAGNOSITICS

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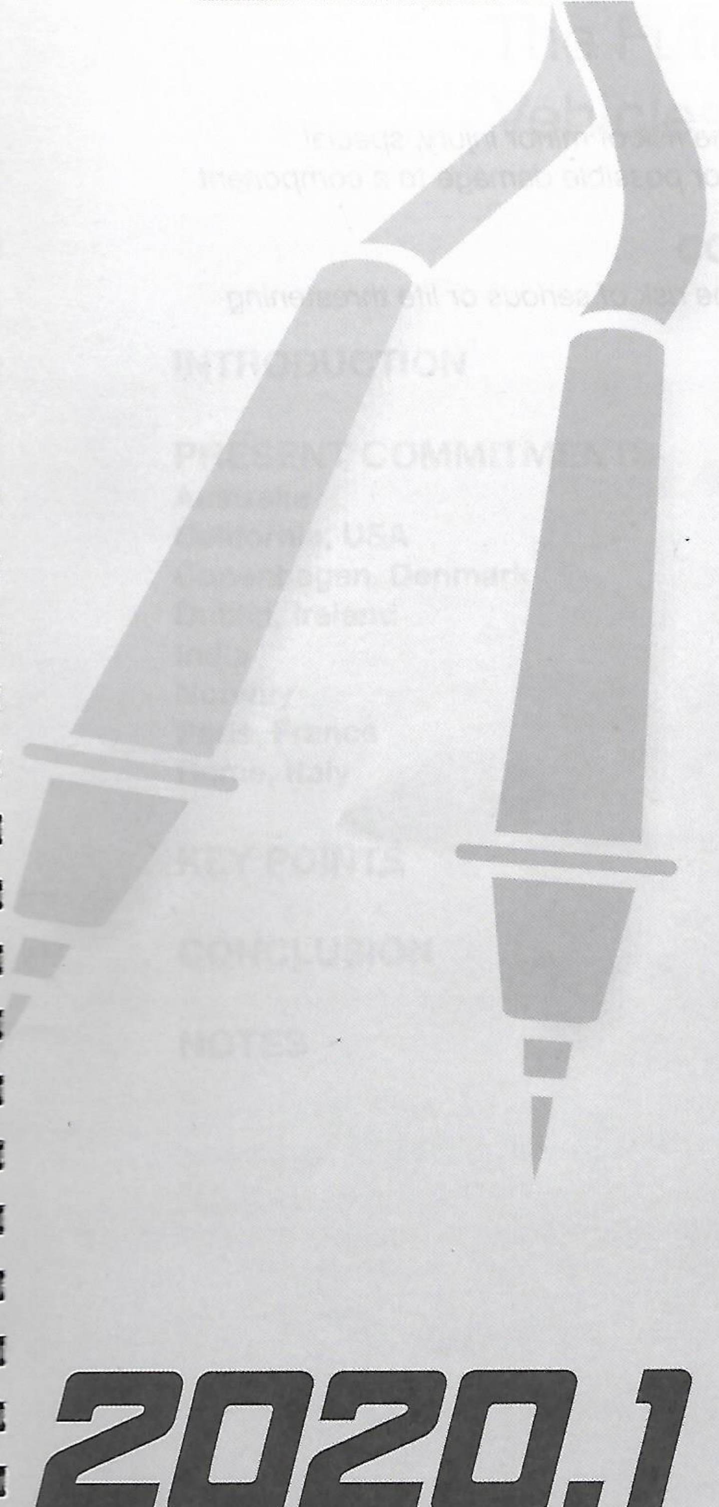

The Future of Diesel Vehicles in Australia

Fuel Injector Comparison Diagnosis

CRD No-Start Diagnosis

Oscilloscope Tips

Traditional CRD Injector Testing Methods

2020.1

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LOOK FOR THESE SYMBOLS THROUGHOUT THE MANUAL

ⓘ	*Note:*	*Indicates a point of interest*
⚠	*Caution:*	*Indicates the risk of minor injury, special procedure or possible damage to a component*
⚠	*WARNING:*	*Indicates the risk of serious or life threatening injury*

Section i

The Future of Diesel Vehicles in Australia

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INTRODUCTION

Over the last few years there has been a lot of controversy in the news about the banning of diesel vehicles, particularly in the major capital cities in Europe and elsewhere around the globe. This has been grossly exaggerated. At the time of publication there had been no laws or legislations passed that will outrightly ban diesel vehicles. The reports of bans have been embellished from 'commitments' and 'proposals' made by various politicians on behalf of cities and countries. Most of the 'Diesel Ban' discussion focuses on vehicles within cities, where hybrid and electric vehicles are a realistic alternative to fossil fuel powered vehicles in the foreseeable future. This is not congruent with the use of diesel vehicles in Australia.

PRESENT COMMITMENTS

At present these are some the actual 'Diesel Ban' commitments around the world:

Australia
The only Australian announcements on this topic, was a comment by NRMA (National Roads and Motorists' Association) CEO Rohan Lund who said that Australia needed to be more aggressive with its targets. It is likely that Australia's vehicles will be governed by the countries where they are built rather than by Australian law. There is currently no policy or commitment by the Australian Government to ban or phase out diesel vehicles.

California, USA
The Californian Air Research Board (CARB) an the other US States that use the CARB emission standards have said: "We will strive to make all passenger vehicle sales in our jurisdictions (Zero Emission Vehicles) ZEV's as fast as possible, and no later than 2050."

Copenhagen, Denmark
The mayor of Copenhagen said in 2017 that he would introduce legislation to ban diesel cars in the city after 2018. He only stated his government would ban diesel cars, not Light Commercial Vehicles (LCV's) or Heavy Vehicles (HV's). No such legislation has been introduced yet.

In October 2019 Denmark's Climate and Energy Minister Dan Jorgensen, called for an EU wide ban on Diesel and Petrol cars by 2040. Lithuania, Latvia, Slovenia, Bulgaria and several other countries, however, suggested that more must be done to stop the "carbon leakage" of selling second-hand autos from western Europe to the eastern region.

Dublin, Ireland
The Irish Government promised: "Only new electric vehicles for sale by 2030 and replace all city buses with EV buses by 2018". On October 1st 2019 the Irish Examiner reported that EV bus trials had started, and showed that the electric buses were "feasible option". To date the new electric buses have only been used on a trial basis.

India
The Indian government pledged to be selling only electric powered vehicles by 2030, but added that this was under the provisos that the cost of EV's had dropped enough to make this commitment economical.

PRESENT COMMITMENTS continued...

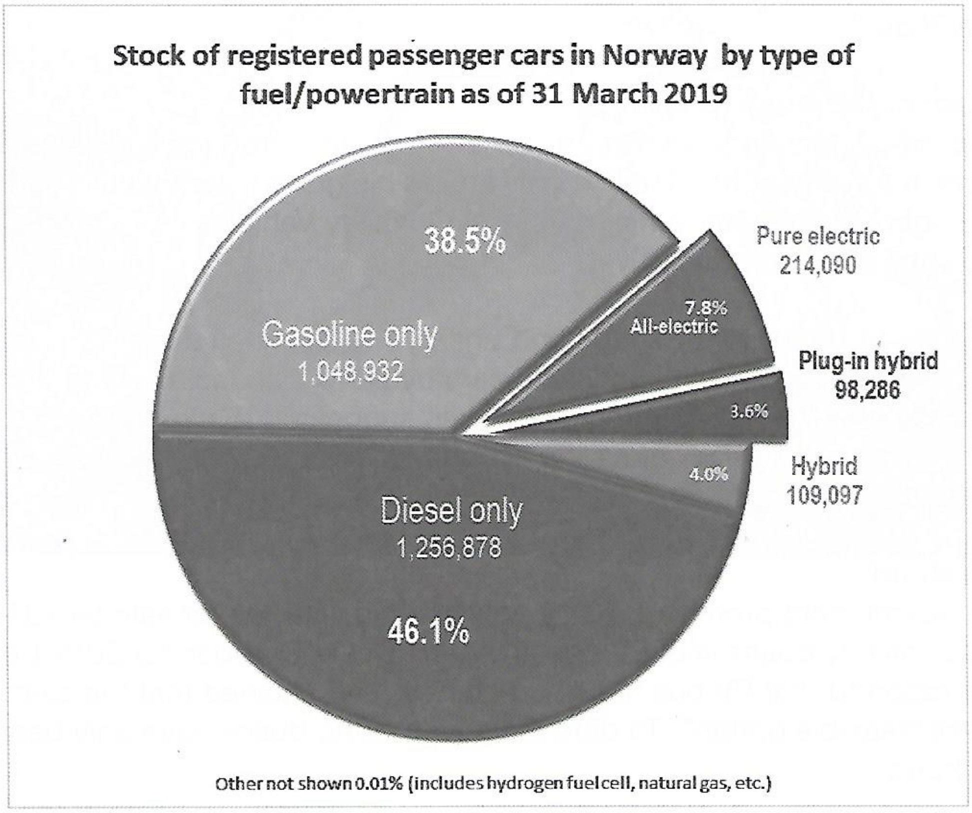
Norway

In one of the most realistic claims, Norwegian politician Vidar Helgesen tweeted, "There is an agreement on a target of zero new fossil-fuel cars sold as from 2025. No outright ban, but strong actions required".

Norway has the highest uptake of EV's but these figures take a long time to water down the ICE powered vehicles on the road.
Percentage of new EV car sales by year:

- 2017 - 20.8%
- 2018 - 31.2%

After a few years of solid EV uptake, 85% of all vehicles on the road are still powered by ICE's and it will take around a decade to reduce that figure to 50%



Graphic by Mariordo (Mario Roberto Durán Ortiz)

Paris, France

The Parisian head of transport stated that the city is planning an exit from fossil energy vehicles. In 2016 he suggested that the city should plan to ban diesel powered engines by 2025 and to ban all internal combustion engines by 2030. This commitment hasn't progressed into legislation.

Rome, Italy

The mayor of Rome shared her plan to ban diesel cars from the city centre by 2024, on her Facebook page in 2018. No legislation has been introduced yet. Her ban was only in regards to cars and the city centre.

KEY POINTS

- No laws have been set for this anywhere in the world
- A number of cities/countries have made 'commitments' to reduce the number of ICE's in their provinces.
- Most discussion is around diesel cars which have been popular in Europe, in Australia we mostly have diesel LCV's, SUV's and HV's
- Porsche canned the Macan diesel because of a software cheat issue not because of pending diesel ban.
- Euro makers have always focused on latest technology and their push into the hybrid and EV industry is consistent with their business direction and not due to future bans.
- Because the cost of EV's is currently higher than ICE equivalent's buyers with a higher disposable income can afford to adopt the technology more easily than other consumers. This has been reflected in sales and therefore in development.

CONCLUSION

While there needs to be cleaner vehicles with a significant reduction in emission and fossil fuels on our roads, the strongest government commitments, incentives and laws will take many years to have a real effect. In Australia the average age of vehicles on the road is 10.2 years. There are currently 19.5 million registered vehicles on our roads and 10 million of those were built before 2010. Furthermore in 2018 the number of diesel powered vehicles increased to 24.6 percent of the national fleet.

What do all these statistics mean? With no fixed legislation on banning diesels, increasing sales and a national fleet that will take at least a decade to be halved, the number of diesel powered vehicles entering independent workshops will be increasing over the next 10 years and it may be another 10 years after that before they begin to very slowly deplete from the Australian market.

ultimate
unleaded
renewable ethanol
ultimate
unleaded
Warning Diesel
diesel
ultimate diesel

NOTES

Section ii

Fuel Injector Comparison Diagnosis

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INTRODUCTION

Diagnosing CRD Fuel Injectors can be a difficult task. The traditional methods are:

1. Fuel Adaptation (Correction Value) data via a Scan Tool
2. Back leakage analysis

Why are these methods are still the best diagnostic tools? Because they are the most likely methods to have OE Manufactures data for. Allowing for a comparison against what the vehicles makers recommends (see Chapter 5. for details of these testing procedures from previous training clinics).

But what happens when these tests are inconclusive or if you can't do a Back Leakage Test because the fuel return circuit is integrated into the cylinder head? This is an extremely common position that technicians often find themselves in. On the following pages we'll explore other procedures to assist with the elusive diagnosis and how using some oscilloscope features can provide additional evidence that may help to pinpoint the cause.

Additional methods:

- Component relocation
- Comparing injector control
- Compression vs Cylinder Balance
- Fuel rail pressure analysis
- Injection pressure ripples
- Back leakage pressure analysis

COMPONENT RELOCATION

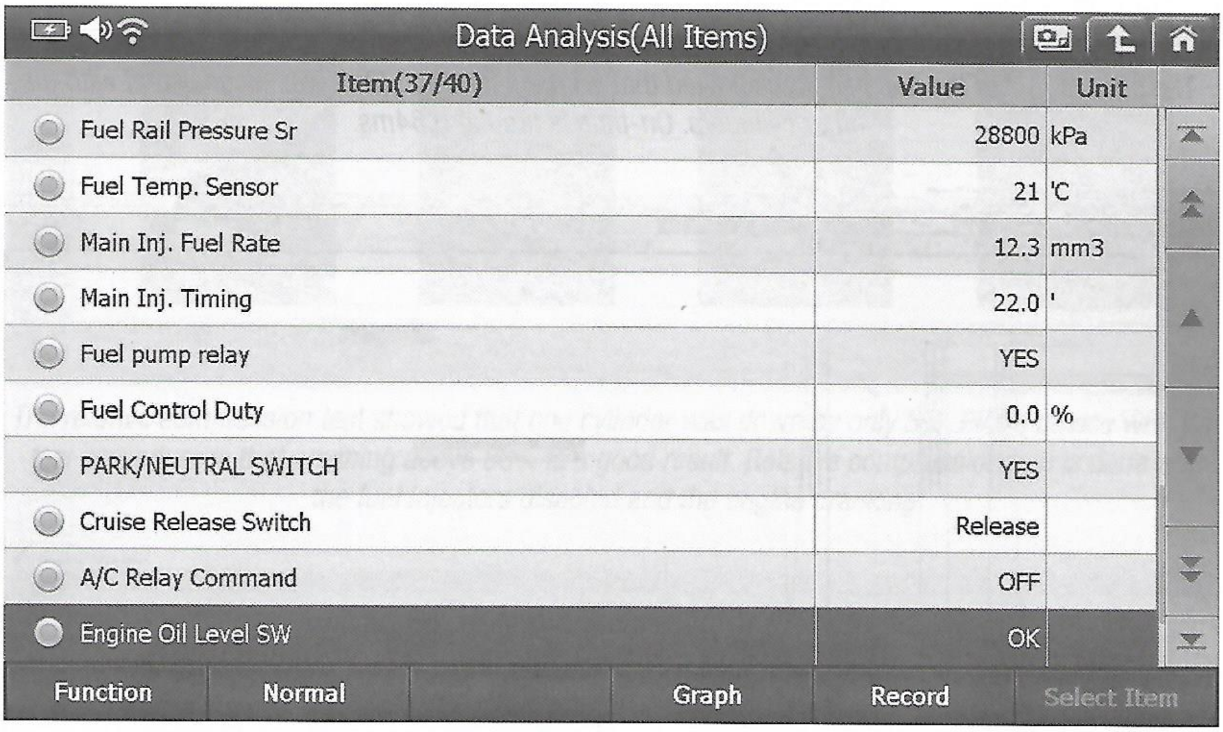
One way to confirm or rule out a faulty injector as the cause of a particular fault is to move the fuel injector to a different cylinder and check to see if the fault follows the injector to its new location. Unfortunately with CRD injectors this can be a very difficult and uneconomical task for many reasons. This method can be a very costly but conclusive way to achieve a diagnosis.

COMPARING INJECTOR CONTROL

It would be helpful if the voltage control of CRD Injectors could be analysed with an oscilloscope in much the same way as you would approach the diagnosis of a petrol fuel injector. However, CRD injectors use indirect control of the Injector Nozzle so this method provides little clarity as to the actual injection event. Complex multiple injections, as well as short injection periods, means that injector pulse width analysis is complex and unreliable. For this, the best measurement is the correction value data on a compatible scan tool.

However, manufacturers do not always provide individual correction values. In these cases the injector on time may indicate compensation of a particular cylinder by the ECU.

For this example a Holden Captiva was found to have rough idle and reduced performance. Soot build up on the tailgate also suggested that black smoke was being emitted from the exhaust. The scan tool data only provided an overall main injection rate.

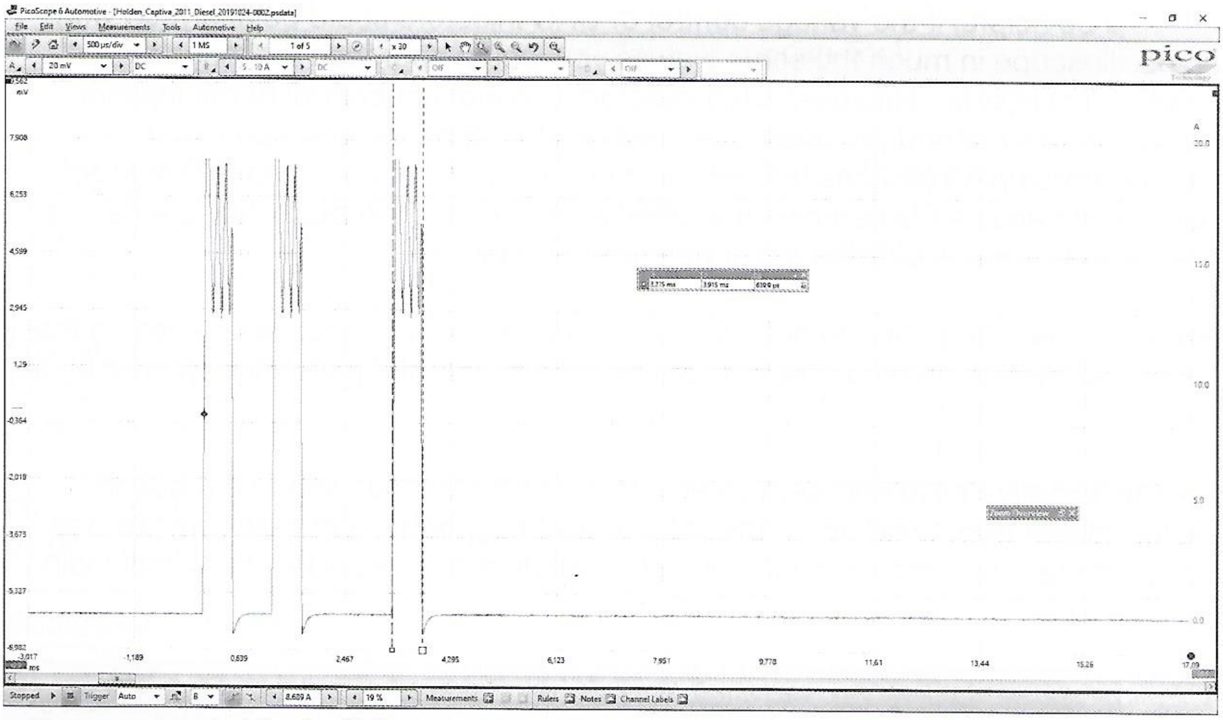


Data Analysis(All Items)

Item(37/40)	Value	Unit
Fuel Rail Pressure Sr	28800	kPa
Fuel Temp. Sensor	21	'C
Main Inj. Fuel Rate	12.3	mm3
Main Inj. Timing	22.0	'
Fuel pump relay	YES	
Fuel Control Duty	0.0	%
PARK/NEUTRAL SWITCH	YES	
Cruise Release Switch	Release	
A/C Relay Command	OFF	
Engine Oil Level SW	OK	

The Scan Tool data from a Holden Captiva 2011 2.0L Z20S1 CRD, shows only a single parameter for Main Inj. Fuel Rate

COMPARING INJECTOR CONTROL continued...


PicoScope 6 Automotive - [Holden_Captiva_2011_Diesel_20191024-0002.psdata]
File Edit Views Measurements Tools Automotive Help
500 µs/div
1 MS
1 of 5
x 30
20 mV
DC
5...10 A
DC
Off
Off
pico
mV
7,908
6,253
4,599
2,945
1,29
-0,364
-2,018
-3,673
-5,327
-6,982
A
20.0
15.0
10.0
5.0
0.0
3,275 ms
3,915 ms
639,9 µs
-3,017
-1,189
0,639
2,467
4,295
6,123
7,951
9,778
11,61
13,44
15,26
17,09
ms
Stopped
Trigger
Auto
B
8,609 A
19 %
Measurements
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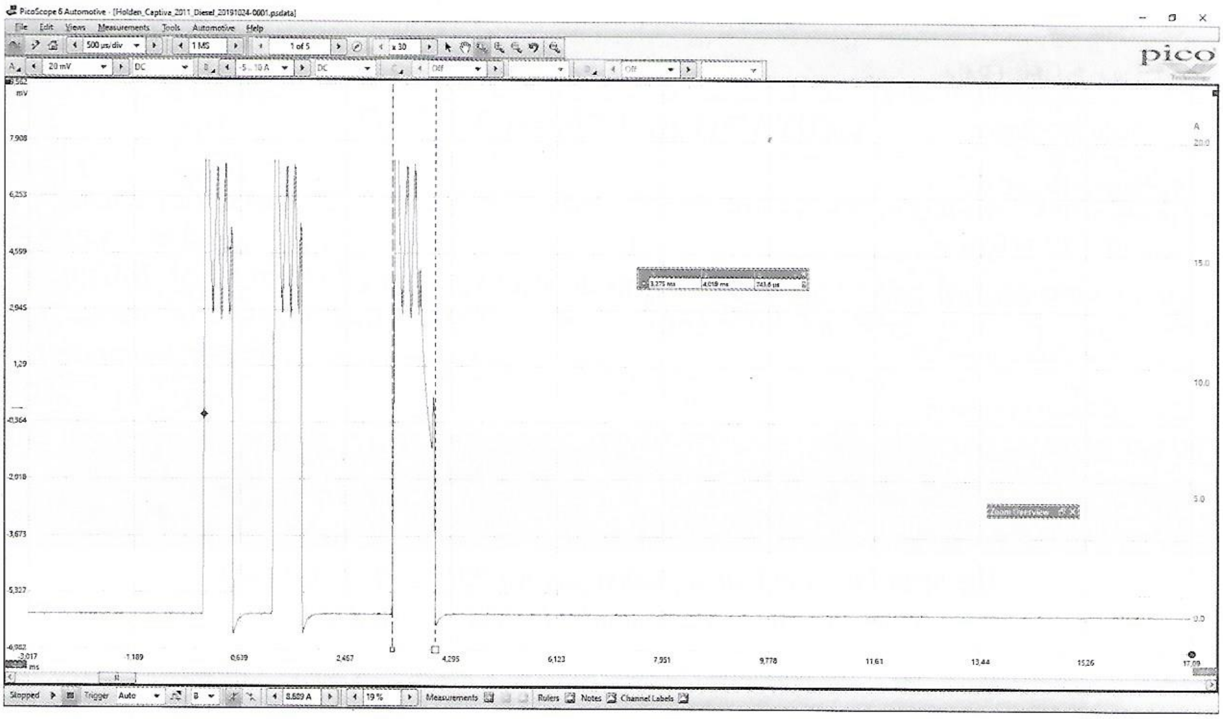
The current test of the fuel injectors showed that #3 main injection (3rd) was inconsistent with the other cylinders. On-time is around 0.64ms.


PicoScope 6 Automotive - [Holden_Captiva_2011_Diesel_20191024-0001.psdata]
File Edit Views Measurements Tools Automotive Help
500 µs/div
1 MS
1 of 5
x 30
20 mV
DC
5...10 A
DC
Off
Off
pico
mV
7,908
6,253
4,599
2,945
1,29
-0,364
-2,018
-3,673
-5,327
-6,982
A
20.0
15.0
10.0
5.0
0.0
3,275 ms
4,019 ms
743,6 µs
-3,017
-1,189
0,639
2,467
4,295
6,123
7,951
9,778
11,61
13,44
15,26
17,09
ms
Stopped
Trigger
Auto
B
8,609 A
19 %
Measurements
Rulers
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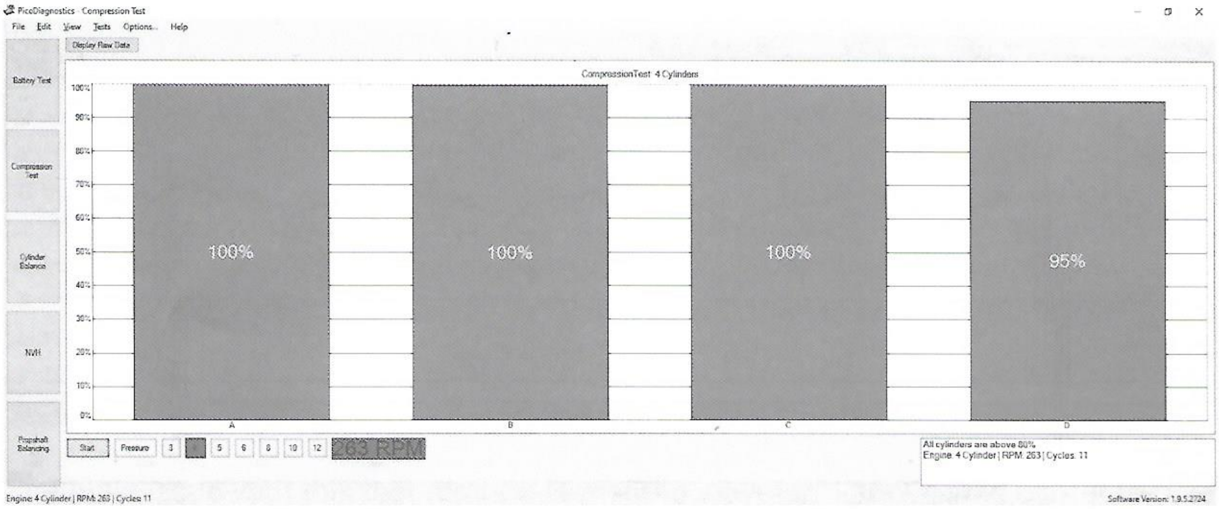
Other cylinders had an on-time of around 0.75ms.

COMPRESSION VS CYLINDER BALANCE

This procedure can be easily performed and provides an graphical representation of the difference between the cylinder compressions while cranking against the cylinder balance while idling. The cylinder compression is tested by disabling the fuel injectors (most easily achieved by removing the Engine ECU fuse or by disconnecting the injector driver/s). Relative compression is sufficient and doesn't need a glow plug to be removed.

The following example is from the same Holden Captiva used previously. The relative compression shows that the cylinders are all very equal with the only variation being that one cylinder is down by 5% (this is well inside the normal range of variation). With the Engine ECU fuse reinserted the cylinder balance shows that one cylinder contribution is down by about 20%. The only significant difference between the conditions under which the two tests are under is the injectors.

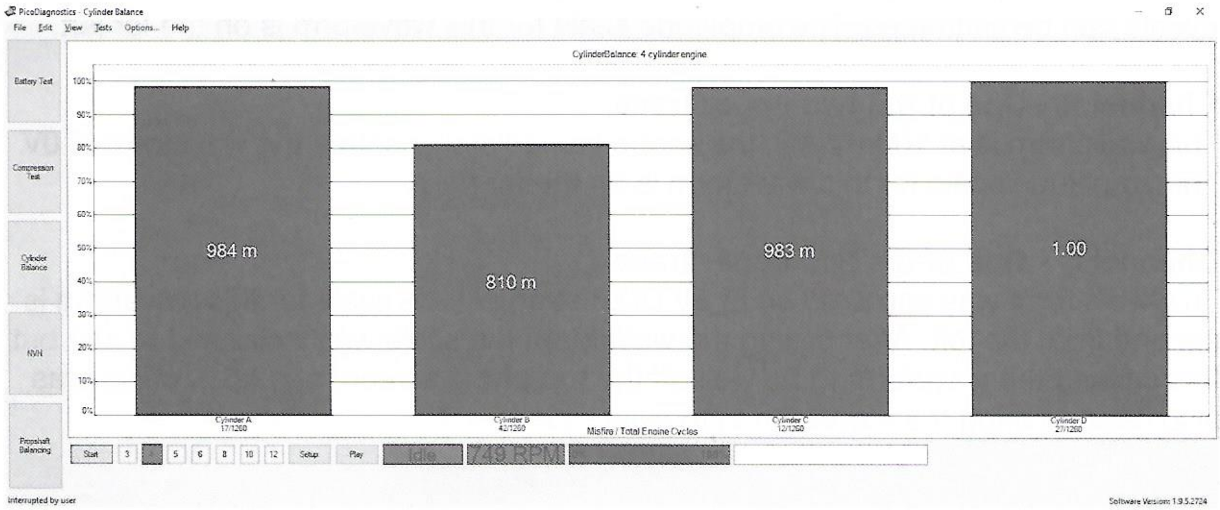

PicoDiagnostics - Compression Test
File Edit View Tests Options... Help
Display Raw Data
Battery Test
Compression Test
Cylinder Balance
NVH
Propshaft Balancing
CompressionTest 4 Cylinders
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
100%
100%
100%
95%
A
B
C
D
Start
Pressure
3
5
6
8
10
12
263 RPM

All cylinders are above 80%
Engine: 4 Cylinder | RPM: 263 | Cycles: 11

Engine: 4 Cylinder | RPM: 263 | Cycles: 11

Software Version: 1.9.5.2724

The relative compression test showed that one cylinder was down by only 5%. Pico's advice with this test procedure is that anything above 80% is a good result. Relative compression test is done with the fuel injectors disabled and the engine cranking.


PicoDiagnostics - Cylinder Balance
File Edit View Tests Options... Help
Battery Test
Compression Test
Cylinder Balance
NVH
Propshaft Balancing
CylinderBalance 4 cylinder engine
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
984 m
810 m
983 m
1.00
Cylinder A 17/1260
Cylinder B 42/1260
Cylinder C 12/1260
Cylinder D 27/1260
Misfire / Total Engine Cycles
Start
3
5
6
8
10
12
Setup
Play
Idle
749 RPM

Interrupted by user

Software Version: 1.9.5.2724

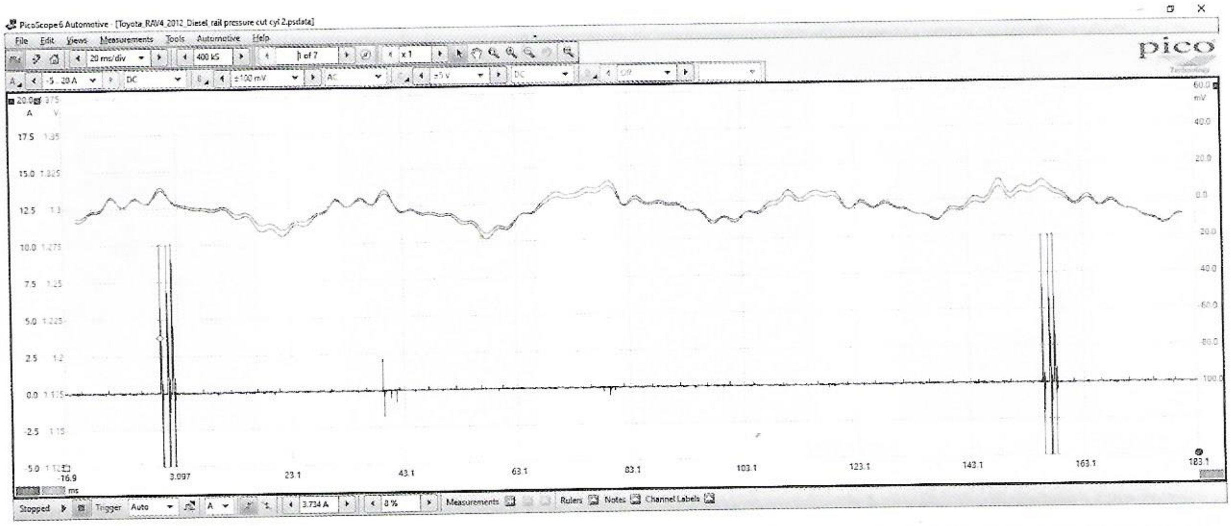
The cylinder balance test showed that one cylinder was down by approximately 20%

FUEL RAIL PRESSURE ANALYSIS

There has been a lot of discussion and experimentation regarding the effects of the injection events on rail pressure throughout the automotive industry. There are many technicians who are using an oscilloscope to monitor the fuel rail pressure. This method can provide a little information, but has its limitations.

It is important to understand that both the fuel going into the Fuel Rail from the High Pressure Fuel Pump and the Fuel Injectors that are drawing fuel from it, will have an effect on the rail pressure.

In order to view the tiny fluctuations in the rail pressure you'll need to measure the voltage on a millivolt scale. For this test it is best to use the voltage at the Fuel Rail Pressure Sensor signal wire with the oscilloscope set to the AC input and in the 100mV range (see Chapter 4 for Oscilloscope Tips).


PicoScope 6 Automotive - [Toyota_RAV4_2012_Diesel rail pressure cut cyl 2.psdata]
File Edit Views Measurements Tools Automotive Help
20 ms/div
400 kS
1 of 7
x 1
-5..20 A
DC
±100 mV
AC
±5 V
DC
Off
pico
20.0 3.75
A V
17.5 1.35
15.0 1.325
12.5 1.3
10.0 1.275
7.5 1.25
5.0 1.225
2.5 1.2
0.0 1.175
-2.5 1.15
-5.0 1.125
60.0 mV
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-16.9 ms
3.097
23.1
43.1
63.1
83.1
103.1
123.1
143.1
163.1
183.1
Stopped
Trigger Auto
A
3.734 A
8 %
Measurements
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Channel A - Lower trace
This waveform is current draw on Injector #1. It is the easiest way to show the timing of the injection events. As this is a 4 Cylinder engine, the other three injection events can be estimated. The amplitude scale for this waveform is on the far left.

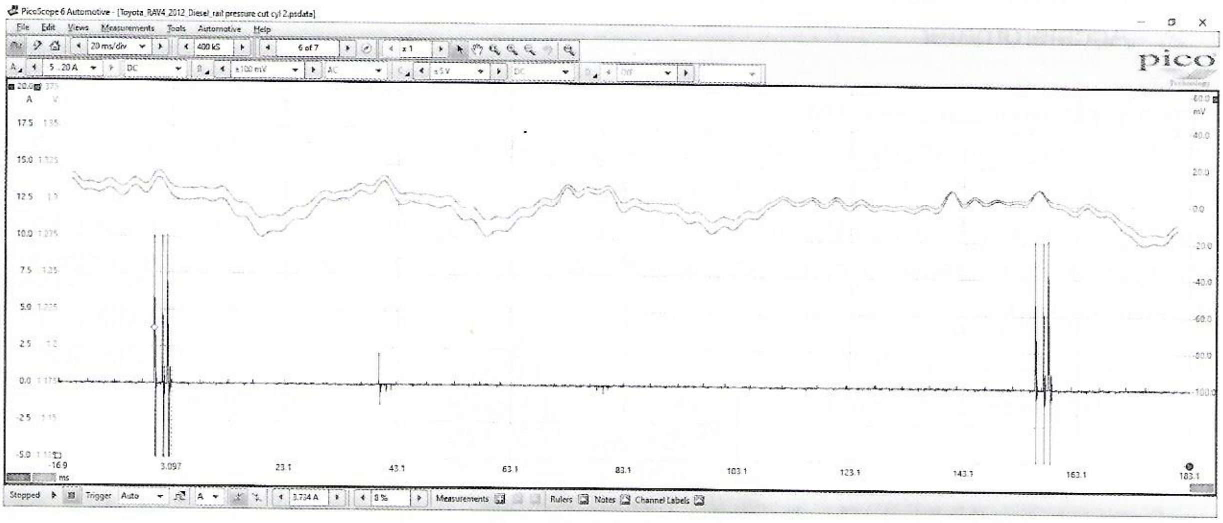
Channel B - One of the two upper trace
This waveform is at 100mV AC, the scope immediately centres the waveform at 0V. The amplitude scale for this waveform is on the far right.

Channel C - One of the two upper trace
This waveform was captured on at 5V DC, the amplitude scale for this waveform is second from the left. After saving the waveform, the scale was increased to x40 but this caused the waveform to be well off the top of the screen, a -12.5% offset was also need to bring the waveform in to view.

FUEL RAIL PRESSURE ANALYSIS continued...

Filtering
Channels B & C also have lowpass filtering activated (see Chapter 4 for Oscilloscope Tips), this allows the scope user to reduce the 'noise' that is displayed on the waveform. This in-built processing filter trims the high and low spikes by averaging out voltages over a small period of time.

The waveforms used for this example were taken from a Toyota Rav4. The initial test (previous page) shows the engine running in a normal condition. The pressure waveform peaks with each injection event. The second waveform (below) was captured with #2 cylinder disabled. In this waveform it is easy to see that the pressure does not drop in the 3rd injection event.


PicoScope 6 Automotive - [Toyota_RAV4_2012_Diesel_rail pressure cut cyl 2.psdata]
File
Edit
Views
Measurements
Tools
Automotive
Help
20 ms/div
400 kS
6 of 7
x 1
A
5..20 A
DC
B
±100 mV
AC
C
±5 V
DC
D
Off
pico
A
V
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
-2.5
-5.0
mV
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-16.9
3.097
23.1
43.1
63.1
83.1
103.1
123.1
143.1
163.1
183.1
ms
Stopped
Trigger
Auto
A
3.734 A
8 %
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The main issue with this test method is that the waveform above was captured with the #2 Injector completely disabled. It is unlikely that an injector that is still functioning even when outside parameters, would make a distinguishable difference to the rail pressure fluctuations.

INJECTION PRESSURE RIPPLES

Another method of identifying injection events that has limited testing is to measured the effect of the injection event on the Injector pipe. It is easy to place a finger upon the injector pipe and feel the ‘tick’ of the injection event. This ‘tick’ is caused by the pressure ripples that vibrate back through the pipe during an injection event.

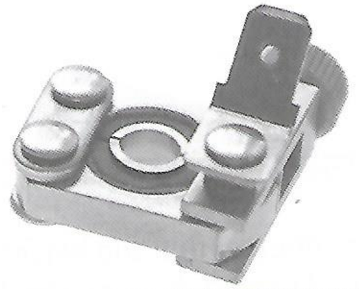
The theory behind this test procedure is that the pressure ripples can be compared between cylinders to assist in pinpointing a faulty injector.

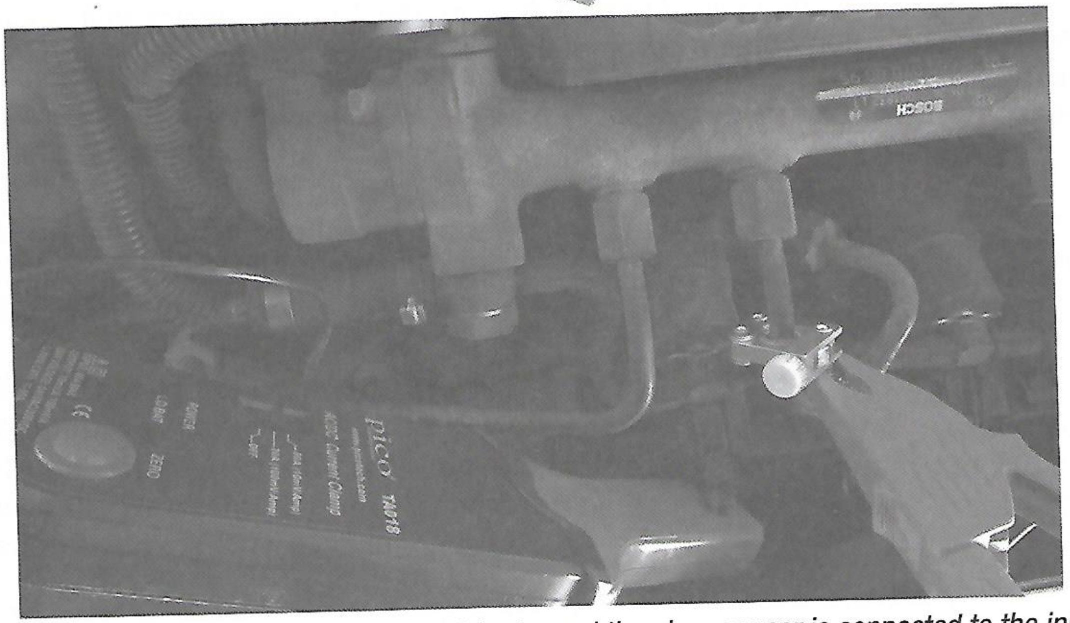
There are two sensing methods that have been used to capture the pressure ripples:

1. Piezo pipe pressure sensor
2. Accelerometer

Piezo pipe pressure sensor

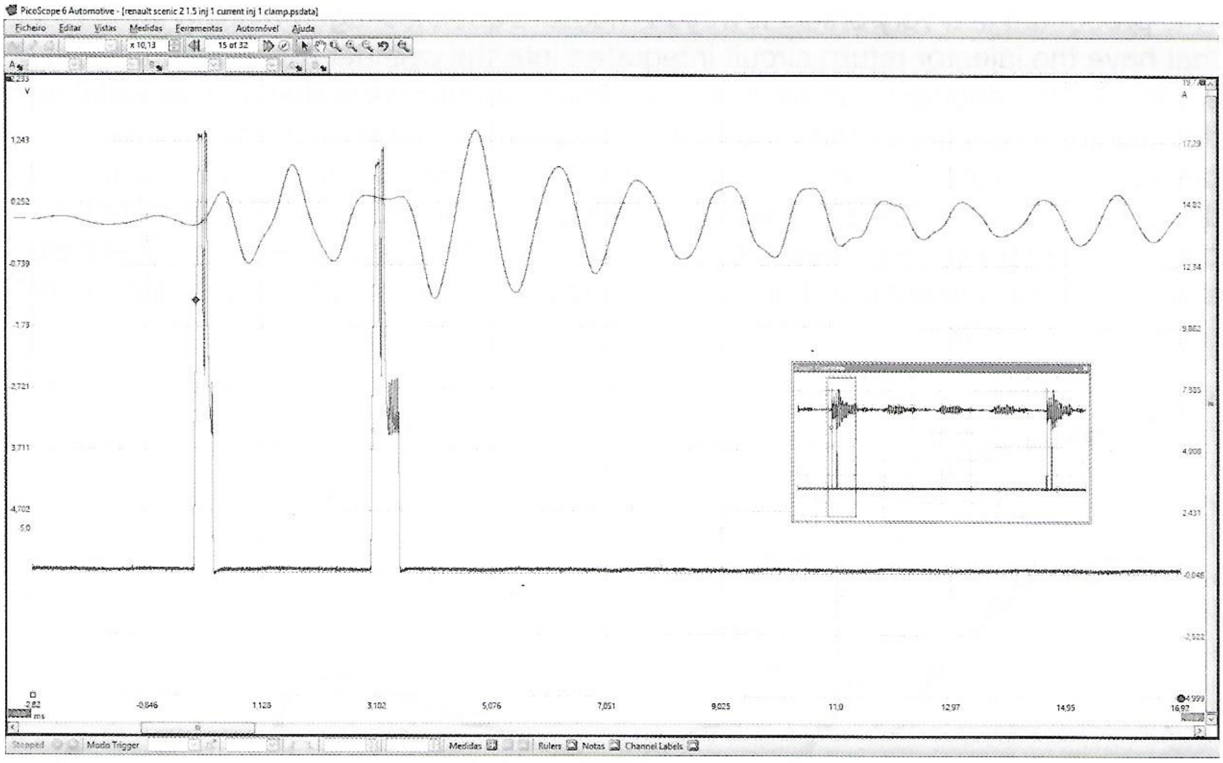
The Piezo pipe pressure sensor was originally designed as a method of measuring the actual injection timing of a mechanically injected diesel engine. Because the piezo crystal exerts a voltage when it has pressure applied to it, the sensor can be connected to an oscilloscope. Where voltage is equal to the rise and fall of pressure within the pipe.





The current clamp is connected to the #1 injector and the piezo sensor is connected to the injector pipe of the same injector.

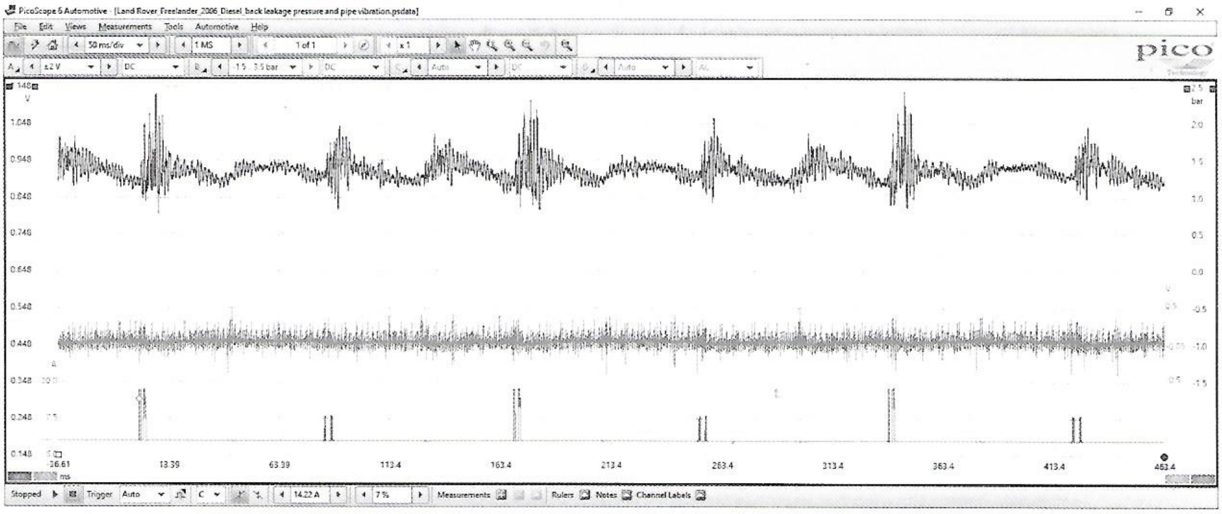
INJECTION PRESSURE RIPPLES continued...


PicoScope 6 Automotive - [renault scenic 2 1.5 inj 1 current inj 1 clamp.psdata]
Ficheiro Editar Vistas Medidas Ferramentas Automóvel Ajuda
x 10,13
15 of 32
2.233
V
1.243
0.252
-0.739
-1.73
-2.721
-3.711
-4.702
5.0
-2.82
ms
-0.846
1.128
3.102
5.076
7.051
9.025
11.0
12.97
14.95
16.92
19.7
A
17.29
14.82
12.34
9.862
7.385
4.908
2.431
-0.046
-2.522
4.999
Stopped
Modo Trigger
Medidas
Rulers
Notas
Channel Labels

The captured waveform shows the vibrations created by the injection event. Vibrations from the other three injection events are also visible due to the transfer back through the shared common rail. The vibrations visible in between the injection events are due to the engine vibrations.

Accelerometer

The following waveform was captured by connecting the Pico NVH accelerometer directly to the scope (instead of through the NVH adapter). The accelerometer method works upon exactly the same principle, except that movement of the pipe is being monitored rather than the expansion of the pipe. This method also highlights a lot more of the engine vibrations.


PicoScope 6 Automotive - [Land Rover_Freelander_2006_Diesel_back leakage pressure and pipe vibration.psdata]
File Edit Views Measurements Tools Automotive Help
50 ms/div
1 MS
1 of 1
x 1
pico
A ±2 V DC
B -1.5...3.5 bar DC
C Auto DC
1.148
V
1.048
0.948
0.848
0.748
0.648
0.548
0.448
0.348
0.248
0.148
2.5
bar
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-36.61
ms
13.39
63.39
113.4
163.4
213.4
263.4
313.4
363.4
413.4
463.4
Stopped
Trigger Auto
14.22 A
7%
Measurements
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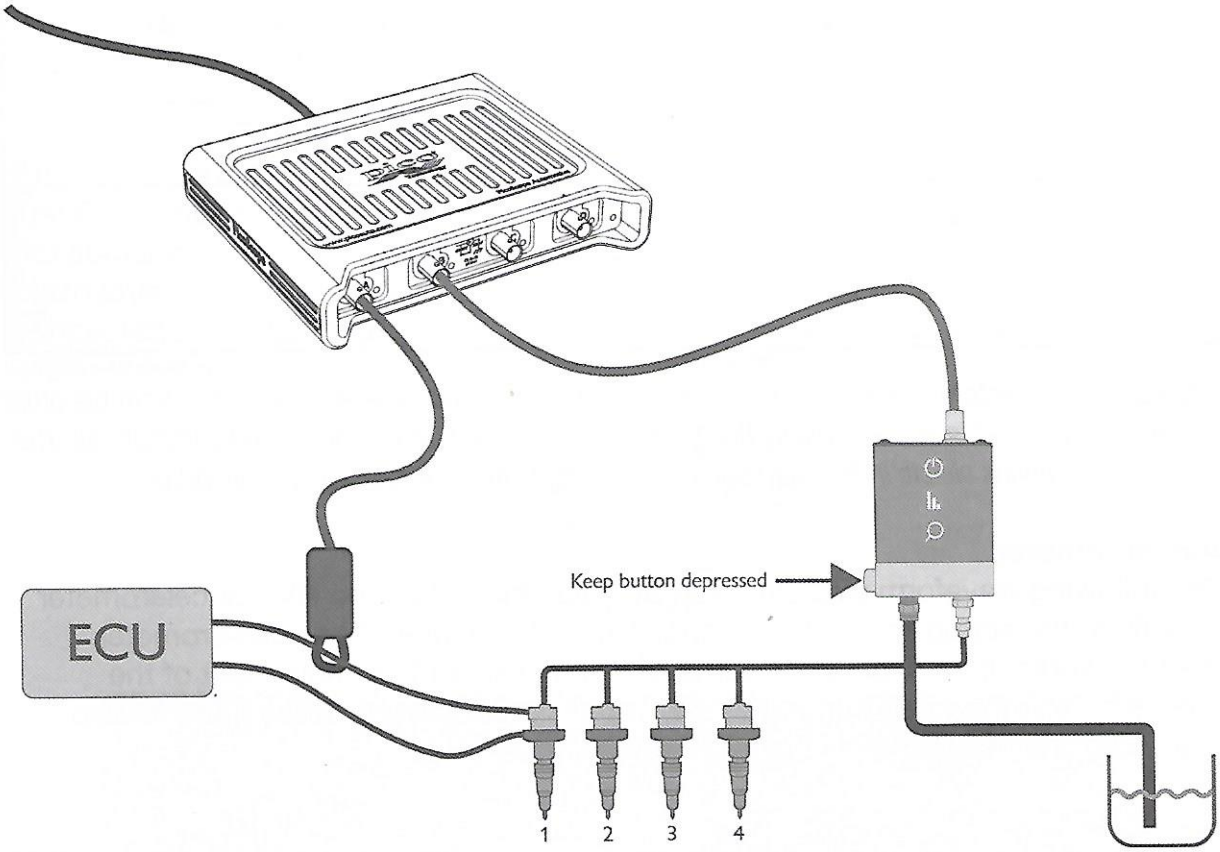
The accelerometer (upper trace) picks up more engine vibrations than the piezo pipe sensor making it harder to identify injector issues.

BACK LEAKAGE PRESSURE ANALYSIS

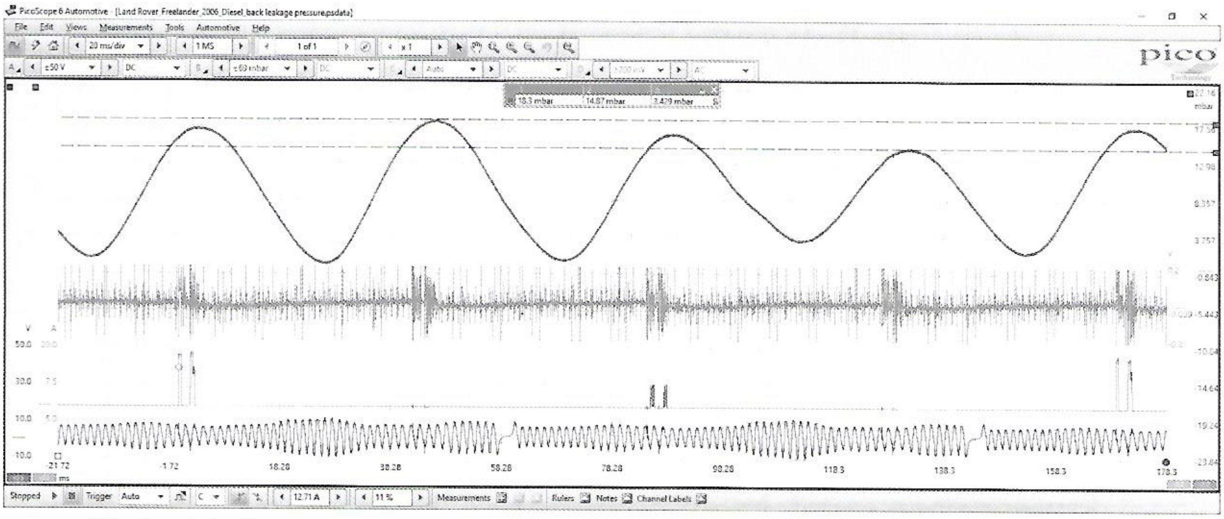
This procedure is a very efficient way to measure back leakage pressure for vehicles that have the injector return circuit integrated into the cylinder head. By connecting a pressure transducer to an oscilloscope. The procedure is carried out by isolating the injector return circuit from the High Pressure Fuel Pump return circuit. The pressure transducer is then attached to the injector return and the outlet pipe from the pressure transducer is vented into a storage container. In order to identify the back leakage pressure pulses, a cylinder identification signal is required. There are a variety of ways to achieve this but monitoring the injector current is an easy and non-invasive method.



BACK LEAKAGE PRESSURE ANALYSIS continued...

The following waveforms were captured on a 2006 Land Rover Freelander, Waveforms present in the picture below are:

- Lower trace - Crankshaft Sensor
- Second trace - Injector #1 Current
- Third trace - Fuel Rail Pressure
- Upper trace - Back Leakage Pressure



PicoScope 6 Automotive - [Land Rover_Freelander_2006_Diesel_back leakage pressure.psdata]

18.3 mbar | 14.87 mbar | 3.429 mbar

File
Edit
Views
Measurements
Tools
Automotive
Help
20 ms/div
1 MS
1 of 1
x 1
±50 V
DC
±69 mbar
DC
Auto
DC
AC
pico
Technology
22.16
mbar
17.56
12.96
8.357
3.757
-0.843
-5.443
-10.04
-14.64
-19.24
-23.84
50.0
30.0
10.0
-10.0
-21.72
-1.72
18.28
38.28
58.28
78.28
98.28
118.3
138.3
158.3
178.3
ms
Stopped
Trigger
Auto
C
12.71 A
11 %
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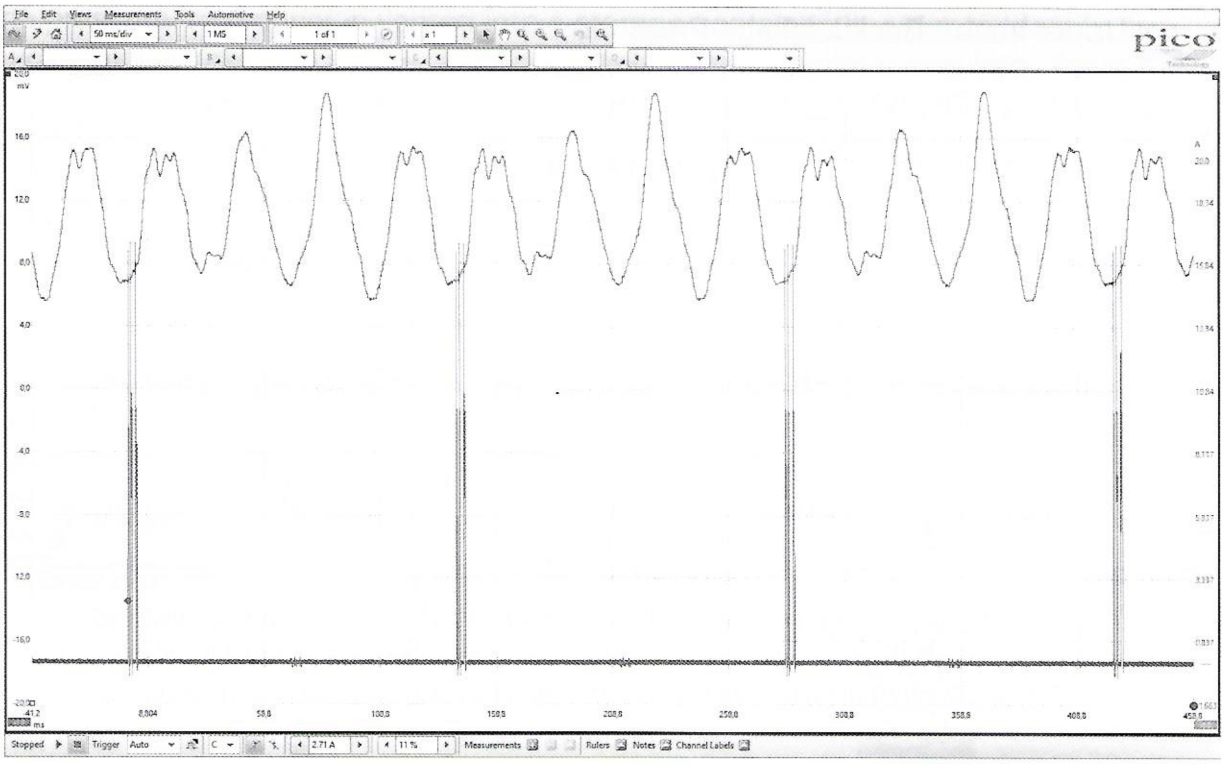
Notes
Channel Labels

The back leakage pressure waveform shows a slight variation across the four cylinders. #3 cylinder is the highest with 18.3 millibar and #2 cylinder is lowest at 14.9 millibar. This shows normal/typical values and this variation does not indicate a fault.

BACK LEAKAGE PRESSURE ANALYSIS continued...

The following waveforms were captured on a 2008 Holden AH Astra. Waveforms present in the picture below are:

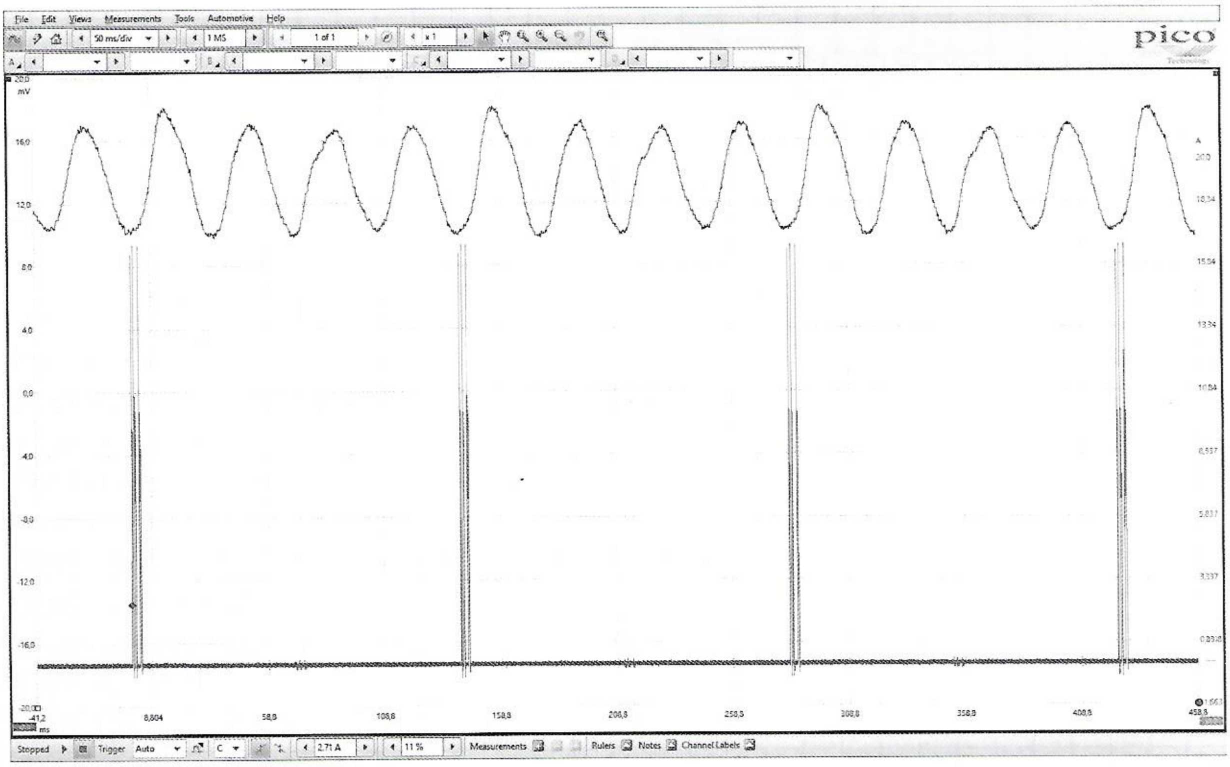
- Lower trace - Injector #1 Current
- Upper trace - Back Leakage Pressure


File
Edit
Views
Measurements
Tools
Automotive
Help
50 ms/div
1 MS
1 of 1
x 1
pico
20.0
mV
16.0
12.0
8.0
4.0
0.0
-4.0
-8.0
-12.0
-16.0
-20.0
A
20.0
18.34
15.84
13.34
10.84
8.337
5.837
3.337
0.837
-41.2
ms
8.804
58.8
108.8
158.8
208.8
258.8
308.8
358.8
408.8
458.8
Stopped
Trigger
Auto
C
2.71 A
11 %
Measurements
Rulers
Notes
Channel Labels

The back leakage pressure waveforms shows significant issues with the feedback from the #1 and #2 injection events.

BACK LEAKAGE PRESSURE ANALYSIS continued...

After replacement of the two faulty injectors (#1 and #2) the back pressure was retested. The result was a vast improvement.


File
Edit
Views
Measurements
Tools
Automotive
Help
50 ms/div
1 MS
1 of 1
x 1
pico
Technology
20,0
mV
16,0
12,0
8,0
4,0
0,0
-4,0
-8,0
-12,0
-16,0
-20,00
A
20,0
18,34
15,84
13,34
10,84
8,337
5,837
3,337
0,8348
1,663
-41,2
8,804
58,8
108,8
158,8
208,8
258,8
308,8
358,8
408,8
458,8
ms
Stopped
Trigger
Auto
C
2,71 A
11 %
Measurements
Rulers
Notes
Channel Labels

The back leakage pressure waveforms shows significant issues with the feedback from the #1 and #2 injection events.

NOTES

Section iii

CRD No-Start Diagnosis

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INTRODUCTION

When a vehicle arrives on the back of a tow truck with a no start situation, choosing where to start your diagnosis can be a challenge. Where is the right place to start? If you check electrical system first and the fault ends up being in the fuel system, can you charge for the time I spent testing the electrical system?"

Because every breakdown situation is unique, there may not be one correct place to start. So the best method is to approach the diagnosis by checking the most likely causes first, while also keeping in mind the easiest testing methods for a fast diagnosis.

Often during no-start breakdowns the combination of component/operation failures and that the battery has often been run down, leads to inaccurate and misleading DTC's being logged. For this exercise it is recommended that the Scan Tool is left parked until the system causing the no start fault has been identified.

The following approach has been developed from a solid understanding of the fundamentals and a fist full of experience:

1. Fuel test
2. Battery - State of Charge (SoC)
3. Battery voltage while cranking
4. Cranking speed (RPM)
5. Engine mechanical (Relative compression)
6. Glow plug operation
7. Fuel rail pressure
8. Injector control

⚠ *Caution:* *Follow this order as each items operation is effected by the result of the previous test!*

Oscilloscope Method

Over this procedure the oscilloscope method will be provided as the first procedure. This is because the combination of tests are most easily performed with the scope and it also provides the best results. Where applicable alternative methods of performing the test will also be provided for those that do not have access to an oscilloscope.

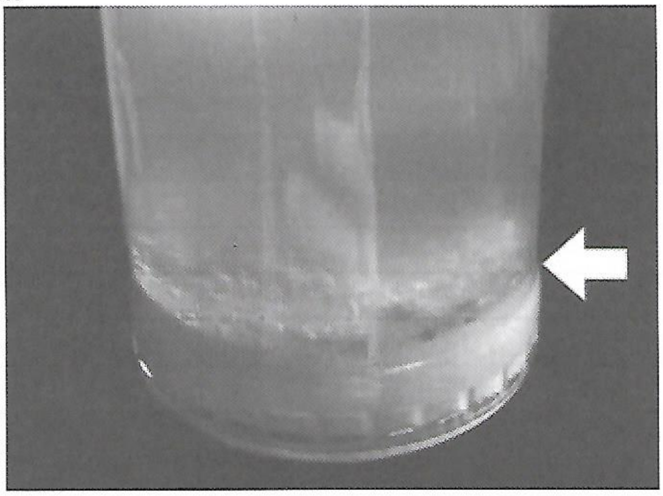
FUEL TEST

Testing the fuel first is important for two reasons:

1. Fuel contamination is a common cause of diesel breakdowns
2. Prevention further damage to the vehicle by continuing to feed contaminated fuel through the vehicles fuel system.

Identify if water is present in the fuel

Drain the fuel filter into a glass beaker or jar and visually check water contamination, if large amounts of water are present check the fuel tank, flush the fuel lines and replace the fuel filter.



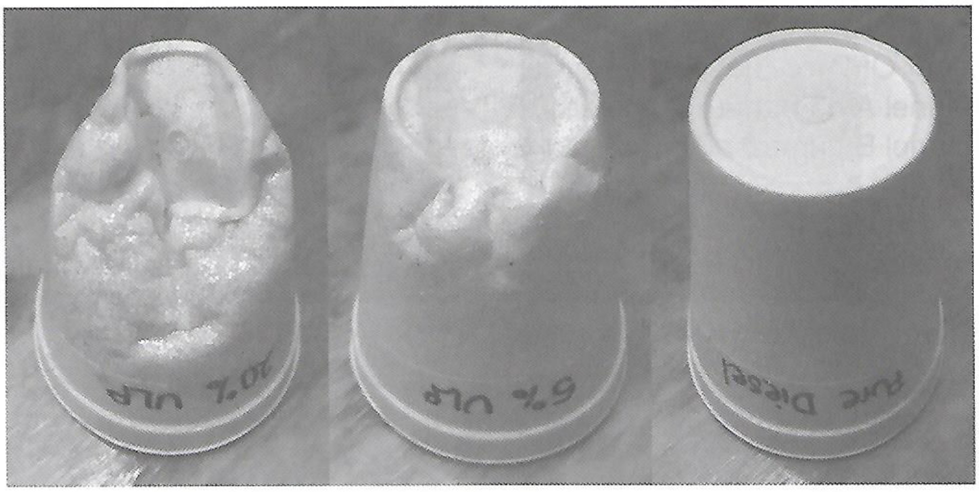
Diesel fuel contaminated with water as drawn from the fuel filter drain

Identify if petrol are present in the fuel

Smell the fuel for presence of petrol. Petrol contamination can usually be smelt even in small quantities. If unsure or if verification is required carry out the following:

Polystyrene cup test:

1. Fill a polystyrene disposable coffee cup with fuel from the fuel filter.
2. Leave over night.
3. Even small traces of petrol will eat away at the inside of the cup.



After 12 hours the petrol will dissolve the cup. Pure diesel will not damage the cup.

BATTERY - STATE OF CHARGE (SOC)

The battery's SoC is important as it creates the benchmark for the following two tests. If the vehicle doesn't meet the minimum results then it is usually best to fit a known good battery while placing the original on a quality charger.

Note: *It is expected for a driver to attempt to start their vehicle multiple times before calling for assistance. So it should be expected that every vehicle that arrives in a no start situation has a battery that is not fully charged.*

A fully charged battery will hold 12.6 Volts.

State of Charge	Voltage	Specific Gravity @ 26.7°C
100%	12.6V	1.270
75%	12.4V	1.230
50%	12.2V	1.190
25%	12.0V	1.145
0%	11.9V	1.100

Typical results:

- If the voltage is above 12.6 Volts: continue to step 2.
- If the voltage is below 12.6 Volts: Charge, substitute or replace the battery then repeat step 1

Note: *Using an oscilloscope to complete this test will allow the technician to carry out tests 2 through 5 with a single procedure.*

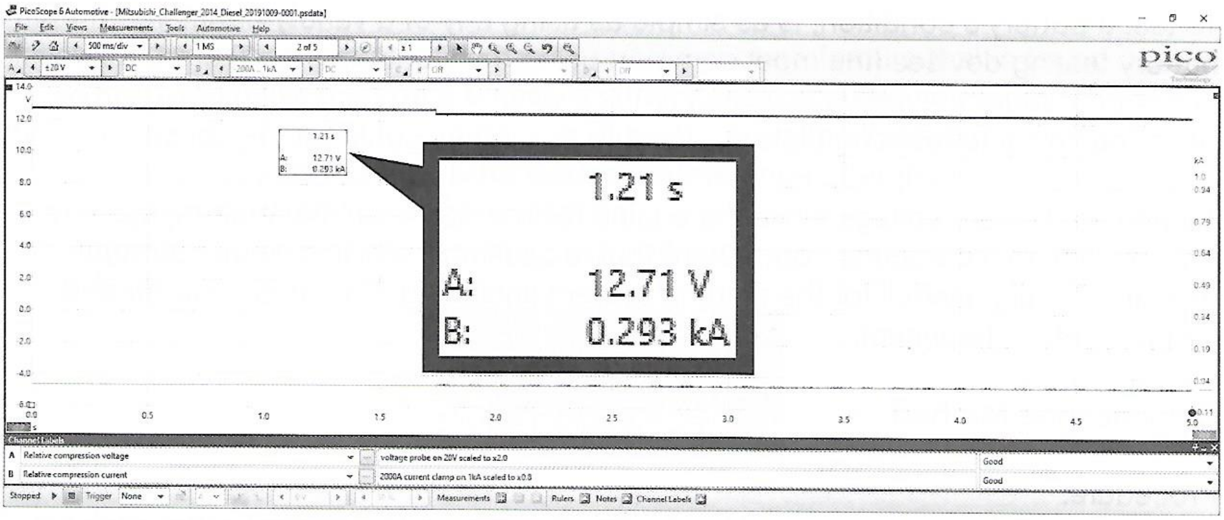
Oscilloscope Method

Scope connections and settings:

- Time scale of 500ms.
- Trigger OFF (so that all data is captured)
- Channel A on battery terminals 0-20V range
- Channel B current clamp on starter lead 2000A range

Procedure:
With the ignition OFF channel A of the scope will indicate the State of Charge (SoC)

BATTERY - STATE OF CHARGE (SOC) continued...


PicoScope 6 Automotive - [Mitsubishi_Challenger_2014_Diesel_20191009-0001.psdata]

1.21 s

A: 12.71 V

B: 0.293 kA

A Relative compression voltage — voltage probe on 20V scaled to x2.0 — Good

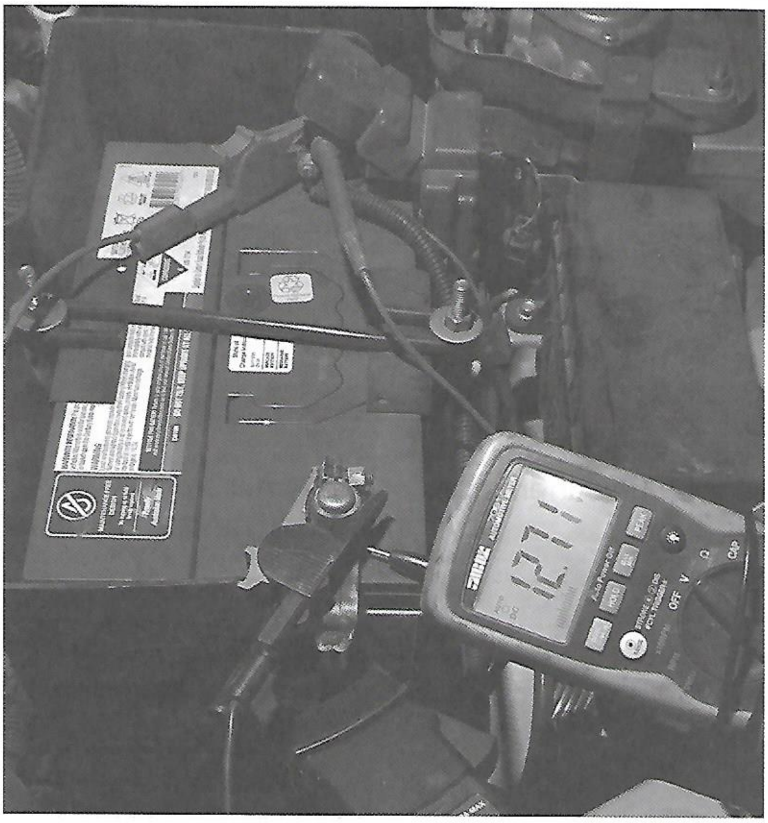
B Relative compression current — 2000A current clamp on 1kA scaled to x0.8 — Good

File
Edit
Views
Measurements
Tools
Automotive
Help
500 ms/div
1 MS
2 of 5
x 1
pico
±20 V
DC
200A...1kA
DC
Off
Off
14.0
V
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
s
kA
1.0
0.94
0.79
0.64
0.49
0.34
0.19
0.04
0.11
Channel Labels
Stopped
Trigger
None
Measurements
Rulers
Notes
Channel Labels

Measuring the battery's State of Charge (SoC) with an oscilloscope.

Multimeter Method

Measure the voltage across the battery terminal with the ignition OFF.



Measuring the battery's State of Charge (SoC) with a multimeter.

BATTERY VOLTAGE WHILE CRANKING

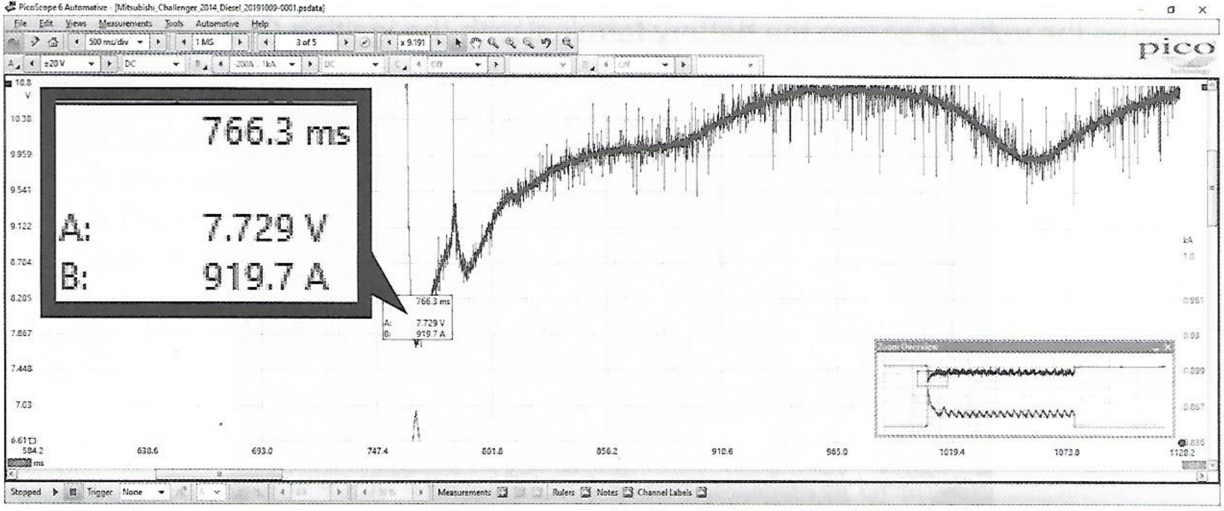
To test a battery's condition, is as simple as using any of a variety of different battery testing devices (the most common being the Conductance Tester). However, in this procedure the desire is to isolate the cause of a no-start condition. At this point the key is to test complete systems to see if they could be the cause.

Testing the battery voltage while the engine is cranking, tests the starting system. It won't isolate a particular component that is causing a starting issue but rather give an overall pass/fail for the starting system (including the battery, starter and components in between).

Oscilloscope Method

Procedure:
Attempt to start the engine, cranking for 3 to 5 seconds is sufficient, then analyse the scope results:

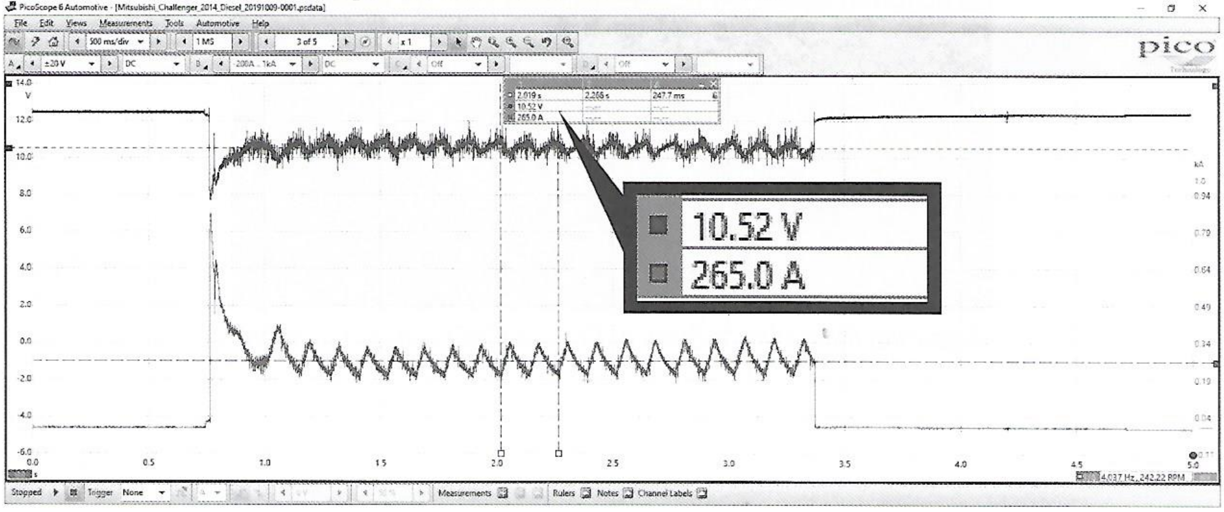
- What is the peak minimum voltage?
- What is the peak current draw of the starter?


PicoScope 6 Automotive - [Mitsubishi_Challenger_2014_Diesel_20191009-0001.psdata]

766.3 ms
A: 7.729 V
B: 919.7 A

File
Edit
Views
Measurements
Tools
Automotive
Help
500 ms/div
1 MS
3 of 5
x 9.191
±20 V
DC
-200A .. 1kA
DC
Off
pico
Technology
10.8
V
10.38
9.959
9.541
9.122
8.704
8.285
7.867
7.448
7.03
6.611
584.2
ms
638.6
693.0
747.4
801.8
856.2
910.6
965.0
1019.4
1073.8
1128.2
kA
Stopped
Trigger
None
Measurements
Rulers
Notes
Channel Labels

- What is the average minimum voltage?
- What is the average current draw of the starter?


PicoScope 6 Automotive - [Mitsubishi_Challenger_2014_Diesel_20191009-0001.psdata]

2.019 s 2.266 s 247.7 ms
10.52 V
265.0 A

File
Edit
Views
Measurements
Tools
Automotive
Help
500 ms/div
1 MS
3 of 5
x 1
±20 V
DC
-200A .. 1kA
DC
Off
pico
Technology
14.0
V
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
0.0
s
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
kA
4.037 Hz, 242.22 RPM
Stopped
Trigger
None
Measurements
Rulers
Notes
Channel Labels

BATTERY VOLTAGE WHILE CRANKING continued...

Multimeter Method

This test can be carried out using the MAX/MIN capture feature that is found on all quality automotive digital multimeter's. Check the operation manual for the multimeter so that the feature is set to the mode where the live reading is displayed while the tool records the MIN/MAX values for reference after the test is completed.

- Test the peak and average voltages
- Using a current clamp test the peak and average current draw

Typical results:

- Peak voltage drop to a minimum of no less than 7 Volts
- Average voltage while cranking shouldn't drop below 10.5 Volts
- Peak amperage should be between 700 and 1000 Amps
- Average amperage while cranking should be between 200 to 300 Amps

Note:

There is a helpful rule for comparing the starter motor current draw to the battery size. The current draw should be approx. 3.5 times the batteries Ah (Amp hour) rating.

265A / 3.5 = 76Ah

76Ah x 3.5 = 265A

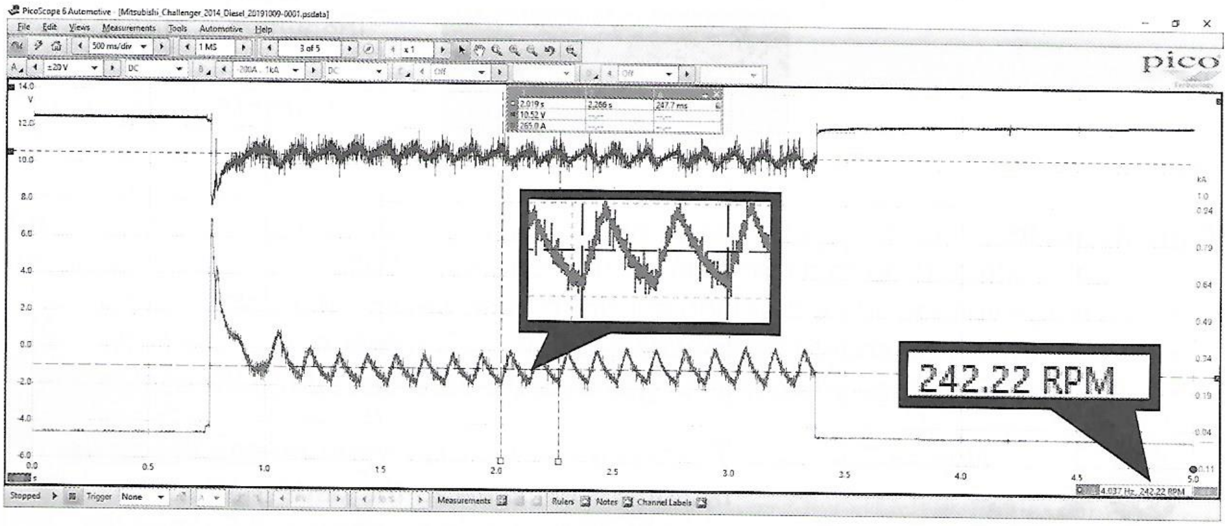
If the Ah is to low or the Amps are too high, investigate wether the battery needs upgrading or if starter motor needs replacing.

ENGINE CRANKING SPEED

Oscilloscope Method

Use the current waveform to calculate the true cranking speed. Adjust a vertical cursor to line up with a compression event somewhere near the centre of the cranking event. Line up a second cursor as follows:

- 4 cylinder engine - 2 events later
- 6 cylinder engine - 3 events later
- 8 cylinder engine - 4 events later


PicoScope 6 Automotive - [Mitsubishi_Challenger_2014_Diesel_20191009-0001.psdata]

	2.019 s	2.266 s	247.7 ms
	10.52 V		
	265.0 A		

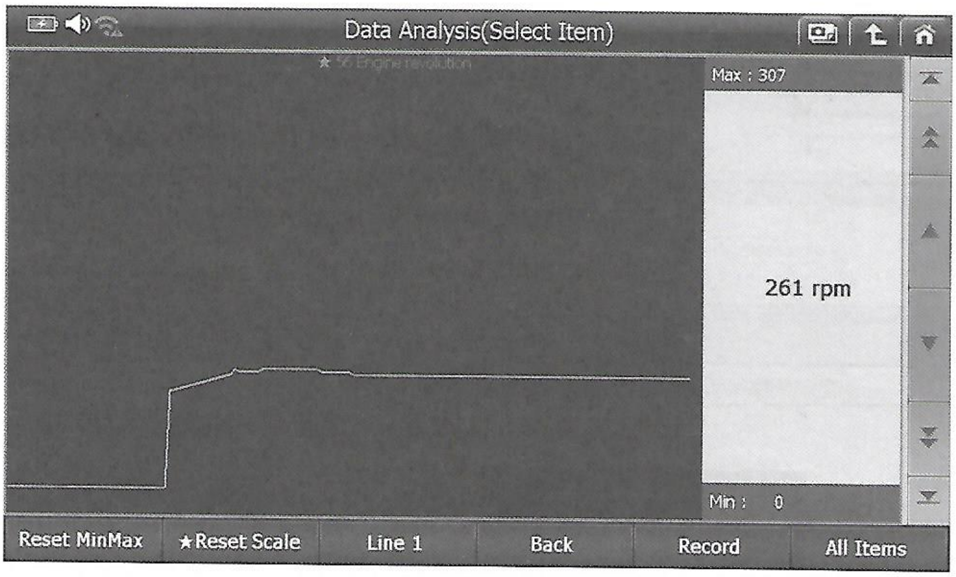
242.22 RPM

4.037 Hz, 242.22 RPM

File Edit Views Measurements Tools Automotive Help
500 ms/div
1 MS
3 of 5
x 1
±20 V
DC
-200A .. 1kA
DC
Off
Off
pico
V
kA
Stopped
Trigger None
Measurements
Rulers
Notes
Channel Labels

Scan Tool Method

From the scan tool data menu select the Engine Speed (RPM) parameter.


Data Analysis(Select Item)

★ 56 Engine revolution

Max : 307

261 rpm

Min : 0

Reset MinMax
★Reset Scale
Line 1
Back
Record
All Items

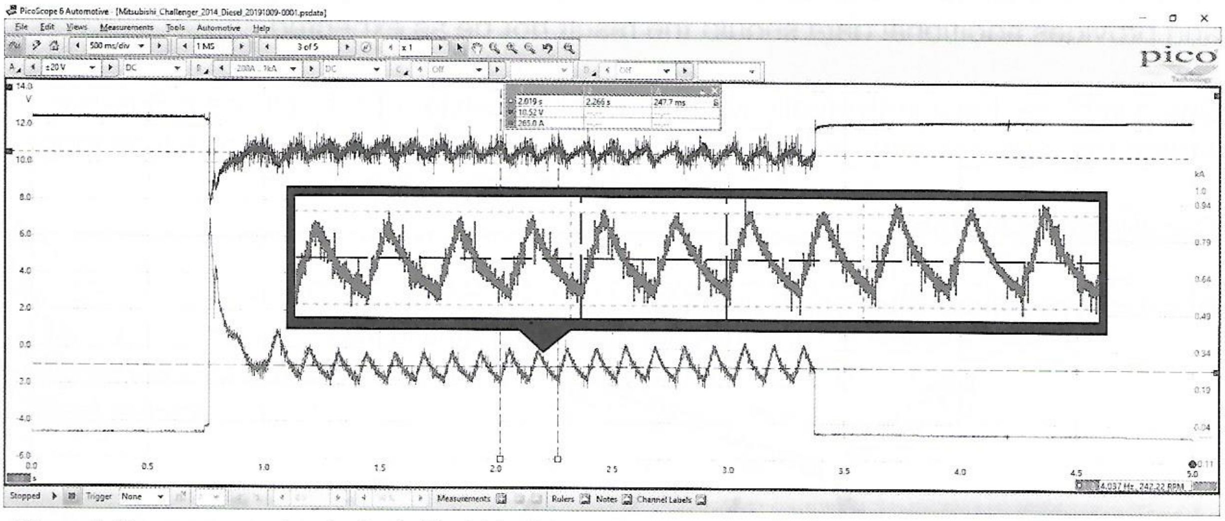
Cranking speed specifications:

- minimum 200rpm
- preferably 250rpm
- vehicles with stop/start preferably 300rpm

RELATIVE COMPRESSION

Relative Compression

In the previous topic we used the Picoscope's built in software for relative compression testing. With this procedure we already have the relative compression data as a result of the cranking amperage. When using the cranking current to establish relative compression look for a consistent sawtooth pattern through the middle of the cranking event.



PicoScope 6 Automotive - [Mitsubishi_Challenger_2014_Diesel_20191009-0001.psdata]

500 ms/div · 1 MS · 3 of 5 · x1

A ±20 V DC · B 200A .. 1kA DC · C Off · D Off

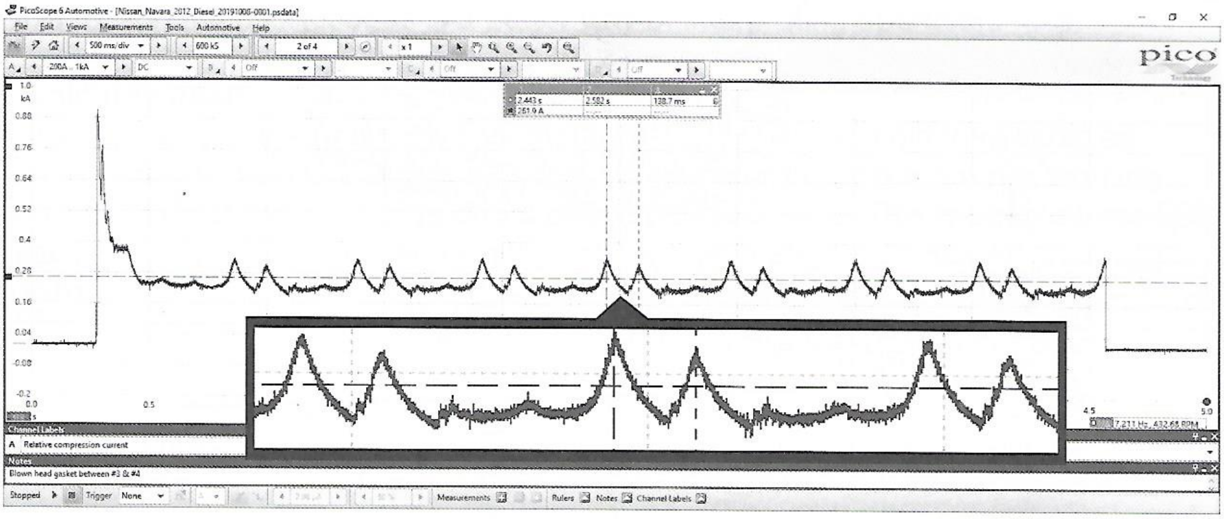
2.019 s | 2.266 s | 247.7 ms
10.52 V
265.0 A

4.037 Hz, 242.22 RPM

Stopped · Trigger None

File
Edit
Views
Measurements
Tools
Automotive
Help
pico
14.0
V
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
-6.0
kA
1.0
0.94
0.79
0.64
0.49
0.34
0.19
0.04
-0.11
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
s
Measurements
Rulers
Notes
Channel Labels

The relative compression test of this 2014 Mitsubishi Challenger 4D56 shows a consistent sawtooth representative of an engine with even compression between cylinders



PicoScope 6 Automotive - [Nissan_Navara_2012_Diesel_20191008-0001.psdata]

500 ms/div · 600 kS · 2 of 4 · x1

A 200A .. 1kA DC · B Off · C Off · D Off

2.443 s | 2.582 s | 138.7 ms
261.9 A

7.211 Hz, 432.65 RPM

Channel Labels
A Relative compression current

Notes
Blown head gasket between #3 & #4

Stopped · Trigger None

File
Edit
Views
Measurements
Tools
Automotive
Help
pico
1.0
kA
0.88
0.76
0.64
0.52
0.4
0.28
0.16
0.04
-0.08
-0.2
0.0
0.5
4.5
5.0
s
Measurements
Rulers
Notes
Channel Labels

The relative compression test of this 2012 Nissan D40 Navara YD25 shows that two cylinders are causing a greater amount of load at the starter motor then the other two. This vehicle turned out to have a cylinder head and gasket failure that caused a combustion leak between cylinders #3 and #4.

Typical results:

- Even 'sawtooth' pattern

GLOW PLUG CONTROL

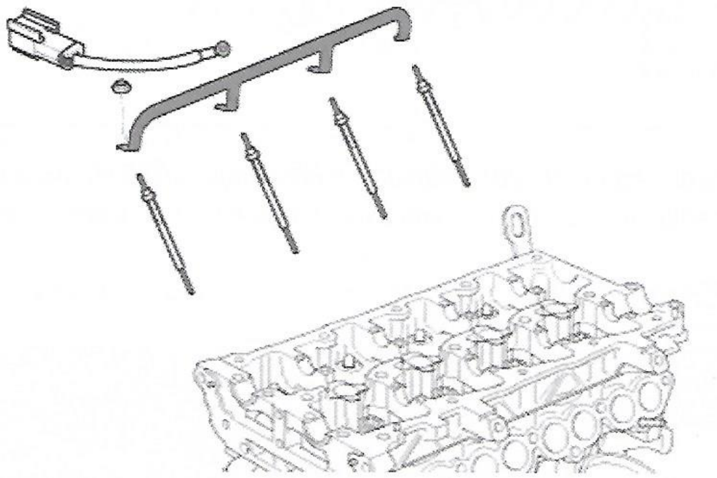
Throughout most of Australia, a glow plug issue will cause a hard starting and/or rough idle concern during cold start. But for some vehicles in some of the colder regions, the failure of the glow system can cause a no-start condition. The easiest way to check glow plug operation is to measure the current flow to the glow plugs.

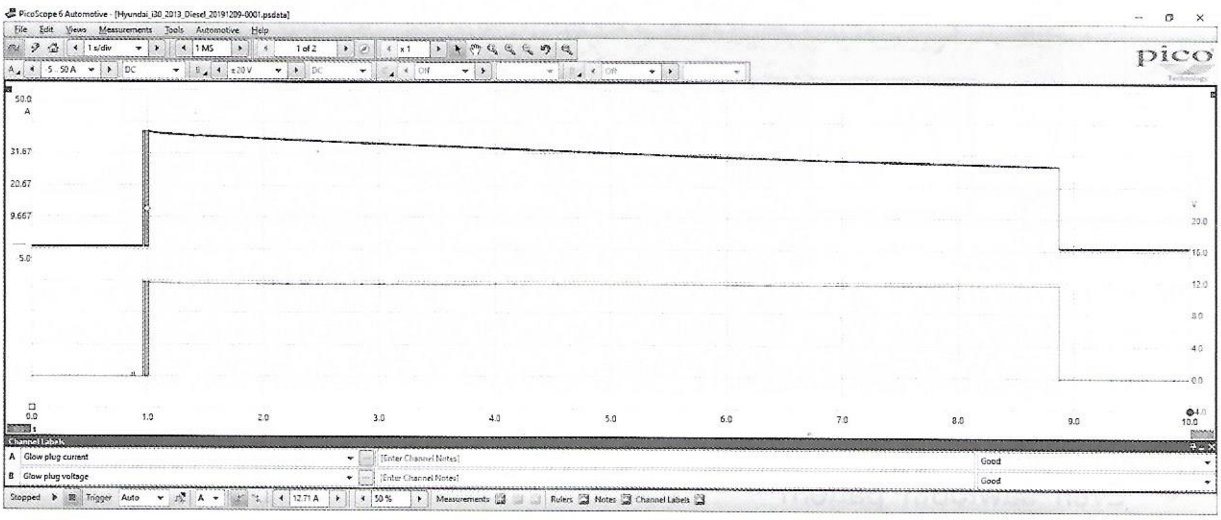
While the current test is all that is needed to identify function, checking voltage and current at the same time takes only a moment longer when setting up the scope and provides additional data should the result not be as expected.

Some vehicles have individually wired glow plugs while others still use a Bus-bar. Attach the current clamp to the power feed to the Bus-bar or by using a fuse loop.

Oscilloscope Method

Bus-bar type glow plug configuration





PicoScope 6 Automotive - [Hyundai_i30_2013_Diesel_20191209-0001.psdata]

1 s/div · 1 MS · 1 of 2 · x 1

A: -5 .. 50 A, DC · B: ±20 V, DC · Off · Off

Channel Labels

A Glow plug current [Enter Channel Notes] Good

B Glow plug voltage [Enter Channel Notes] Good

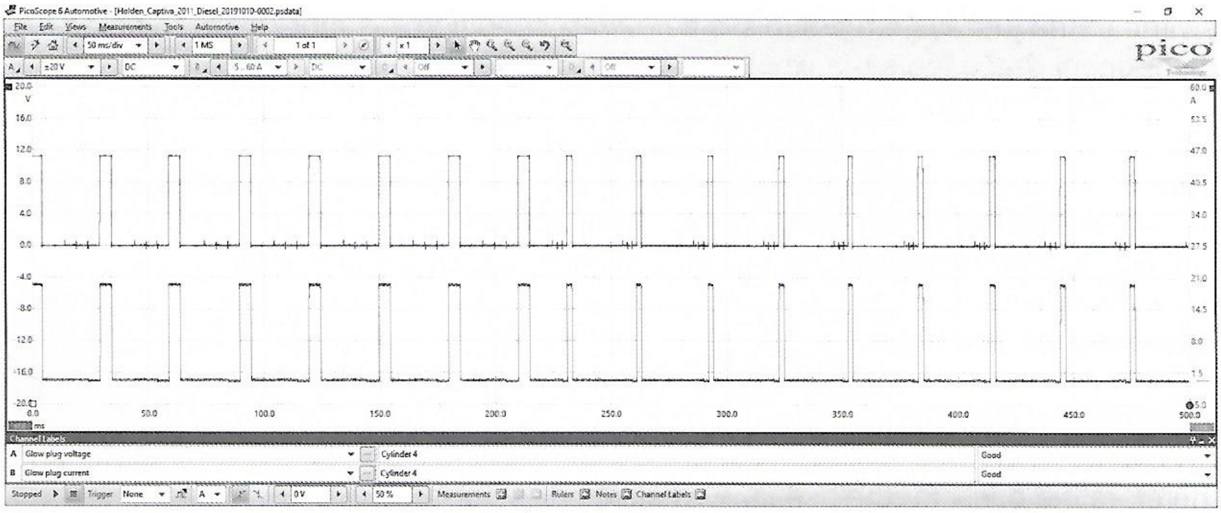
Stopped · Trigger Auto · A · 12.71 A · 50 %

File
Edit
Views
Measurements
Tools
Automotive
Help
pico
50.0
A
31.67
20.67
9.667
5.0
V
20.0
16.0
12.0
8.0
4.0
0.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
s
Measurements
Rulers
Notes
Channel Labels

This capture shows the current draw in upper waveform and the voltage control on the lower. The vehicle was cold but the ambient temperature was around 30°C. On-time is just under 8 seconds, current draw starts at around 40A and then slowly drops to around 25A as the glow plug's resistance increases with temperature.

GLOW PLUG CONTROL continued...

Individually wired


PicoScope 6 Automotive - [Holden_Captiva_2011_Diesel_20191010-0002.psdata]

50 ms/div

1 MS

1 of 1

x1

A ±20 V DC

B 5..60 A DC

C Off

D Off

Channel Labels

A	Glow plug voltage	Cylinder 4	Good
B	Glow plug current	Cylinder 4	Good

Stopped Trigger None A 0 V 50 %

File Edit Views Measurements Tools Automotive Help
pico
20.0 V
16.0
12.0
8.0
4.0
0.0
-4.0
-8.0
-12.0
-16.0
-20.0
60.0 A
53.5
47.0
40.5
34.0
27.5
21.0
14.5
8.0
1.5
-5.0
0.0 ms
50.0
100.0
150.0
200.0
250.0
300.0
350.0
400.0
450.0
500.0
Measurements
Rulers
Notes
Channel Labels

This capture shows the current draw in the lower waveform and the voltage control in the upper. This vehicle uses duty-cycle control and the glow plugs are individually wired through the harness. These waveforms are of cylinder #4 and shows that the duty drops from 20% down to 10%, this is an indicator that the glow plugs are working normally.

Multimeter Method

Using a current clamp, test the current draw. Using a multimeter for current will only give an average current draw (e.g. 10A on a 50% Duty Cycle will average to 5A). For this reason the oscilloscope is a better way of interpreting operation.

Typical results:

While the amperage draw can change dramatically between different vehicles (from under 10A up to 20A per cylinder), an indicator that the system is working normally is that the amperage drops after a period of time. This is because the ECU calculates that there has been significant heat generated and reduces.

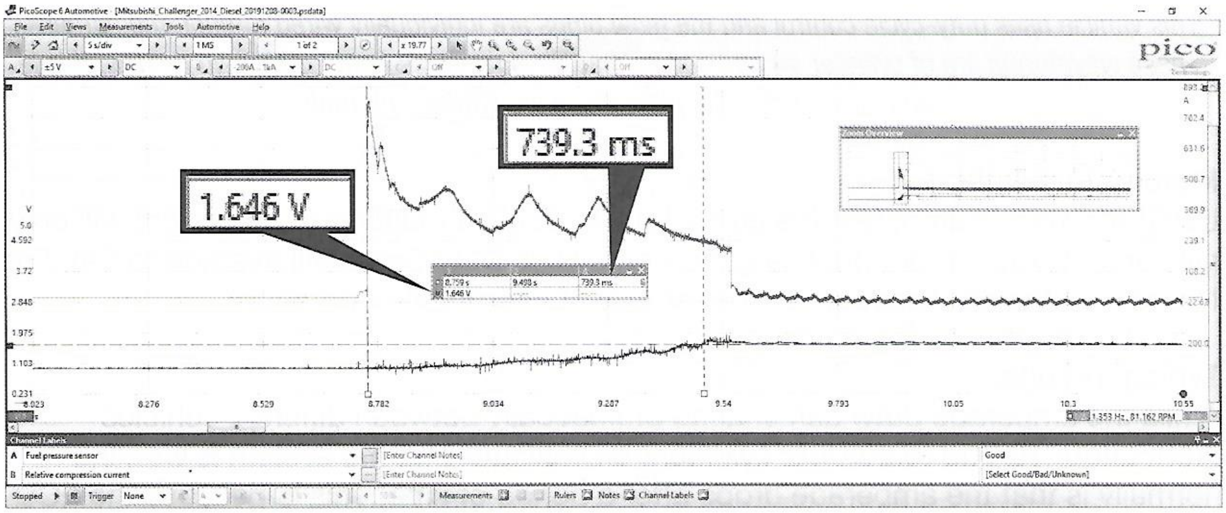
FUEL RAIL PRESSURE

If the no start vehicle has passed the first six tests then the basic electrical and starting systems have been ruled out as potential causes. The focus should now switch to the fuel system. As this is a no-start condition it is more likely to be a component that effects the whole engine rather than individual cylinder related components such as an injector.

Again, focusing on the fact that it is a no-start issue. It is sufficient evidence that if the rail pressure is within tolerance during the ignition on and cranking tests that the entire fuel delivery system back to the fuel tank cannot be the cause.

Oscilloscope Testing

For this procedure the a voltage probe is connected to the Fuel Rail Pressure sensor signal wire and the channel is set to 0-5V. In this test the current clamp was also connected as an easy way to monitor the engagement of the starter motor and therefore the basis for the rise time calculation.



PicoScope 6 Automotive - [Mitsubishi_Challenger_2014_Diesel_20191208-0003.psdata]

A: ±5 V, DC; B: -200A..1kA, DC; 5 s/div; 1 MS; 1 of 2; x 19.77

A Fuel pressure sensor [Enter Channel Notes] Good

B Relative compression current [Enter Channel Notes] [Select Good/Bad/Unknown]

Stopped Trigger None

File
Edit
Views
Measurements
Tools
Automotive
Help
pico
1.646 V
739.3 ms
8.759 s
9.498 s
739.3 ms
V
5.0
4.592
3.72
2.848
1.975
1.103
0.231
8.023
8.276
8.529
8.782
9.034
9.287
9.54
9.793
10.05
10.3
10.55
A
702.4
1.353 Hz, 81.162 RPM
Channel Labels
Measurements
Rulers
Notes
Channel Labels

The Mitsubishi Challenger took 740ms (0.74 seconds) to reach the desired rail pressure for start and idle. The 1.646V correlates to approx. 35Mpa of rail pressure.

Typical Results

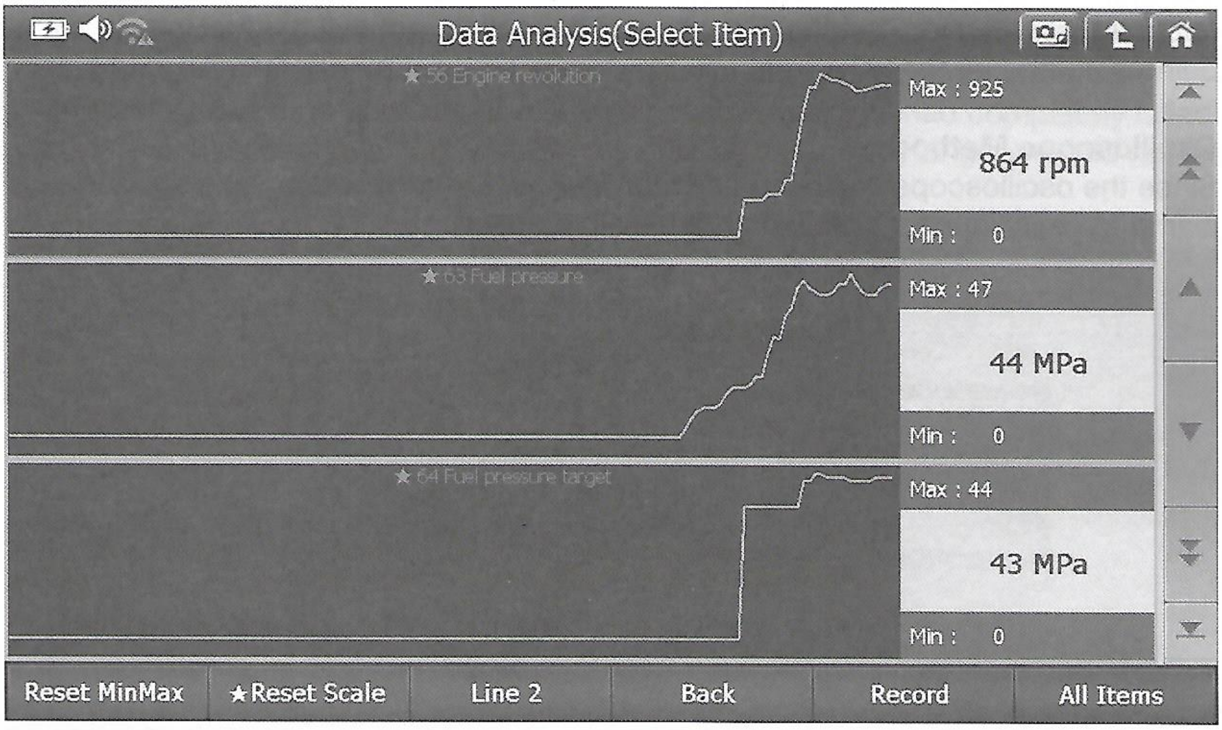
Rise time of fuel pressure should be anywhere from 300ms to a max of 1 second. Typically the normal idling pressure should be achieved within this time.

Shortcut values (accurate enough to rule out system as functional):

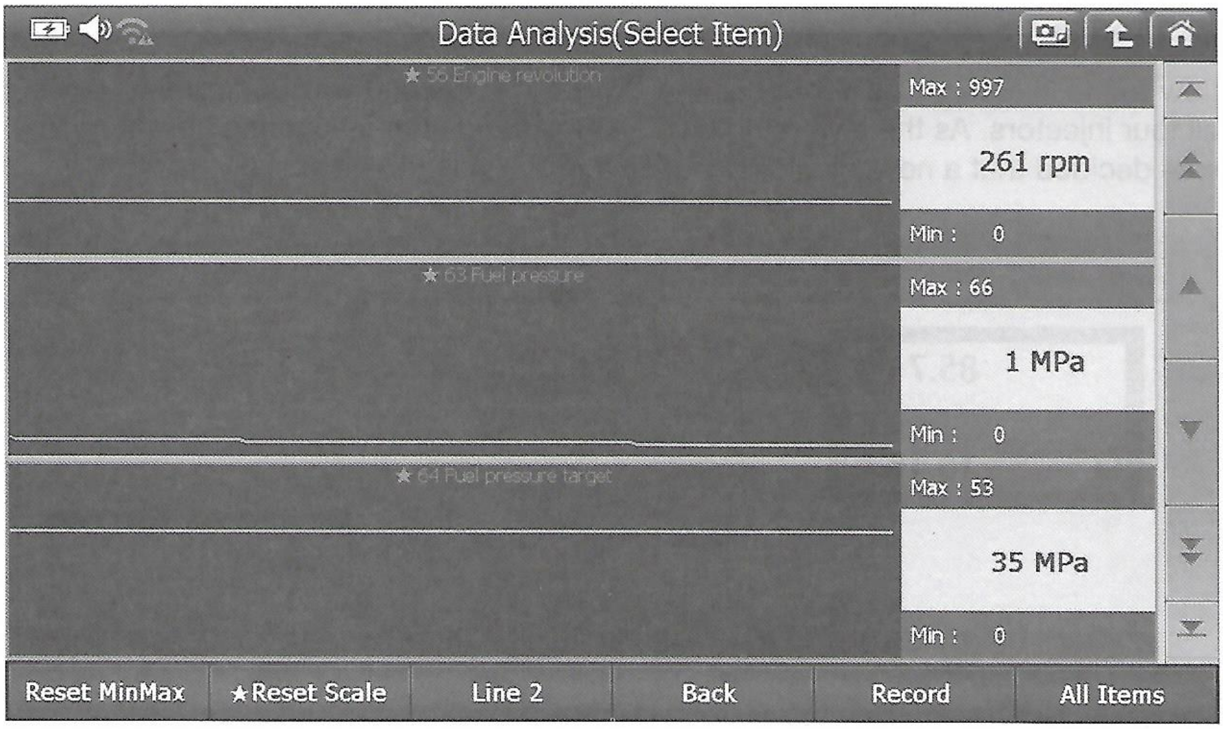
- Bosch system typical 0.5V with ignition on no pressure
- Bosch system should be around 1.0V at idle
- Denso system typical 1.0V with ignition on no pressure
- Denso system should be around 1.5V at idle

FUEL RAIL PRESSURE continued...

Scan Tool Testing


Data Analysis(Select Item)
★ 56 Engine revolution
Max : 925
864 rpm
Min : 0
★ 63 Fuel pressure
Max : 47
44 MPa
Min : 0
★ 64 Fuel pressure target
Max : 44
43 MPa
Min : 0
Reset MinMax
★Reset Scale
Line 2
Back
Record
All Items

This scan tool data represents the same values as the oscilloscope capture on the previous page. The fuel pressure (middle graph) is represented as a steady increase up to the desired value. The scan tool does not provide a time base.


Data Analysis(Select Item)
★ 56 Engine revolution
Max : 997
261 rpm
Min : 0
★ 63 Fuel pressure
Max : 66
1 MPa
Min : 0
★ 64 Fuel pressure target
Max : 53
35 MPa
Min : 0
Reset MinMax
★Reset Scale
Line 2
Back
Record
All Items

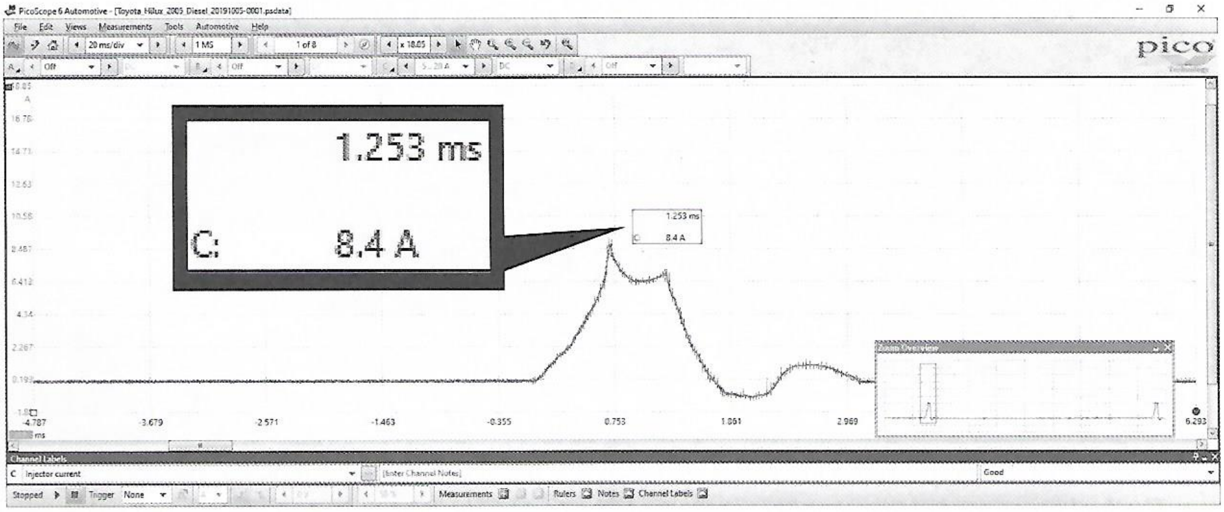
With a restricted fuel supply the scan tool can show the cranking speed (RPM), desired (target) Fuel Pressure and the Actual Fuel Pressure.

FUEL INJECTOR CONTROL

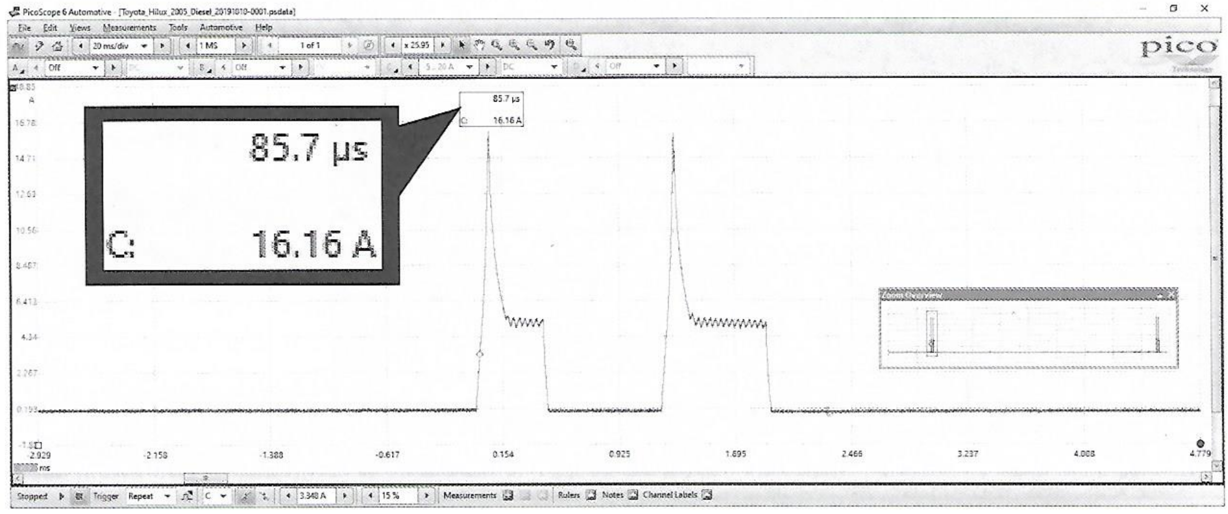
While full injector diagnostics are covered in the previous topic (Chapter 2), through this procedure everything has been ruled out except for fuel delivery from the fuel rail to the combustion chamber. It is necessary now to prove if the fuel injectors are being actuated by the ECU.

Oscilloscope Method

Since the oscilloscope has been used throughout this procedure using the 60A clamp to verify injector operation is a sensible option.


PicoScope 6 Automotive - [Toyota_Hilux_2005_Diesel_20191005-0001.psdata]
File Edit Views Measurements Tools Automotive Help
20 ms/div
1 MS
1 of 8
x 18.05
Off
5...20 A
DC
pico
1.253 ms
C: 8.4 A
Zoom Overview
-4.787
-3.679
-2.571
-1.463
-0.355
0.753
1.861
2.969
6.293
ms
Channel Labels
C Injector current
Good
Stopped
Trigger None
Measurements
Rulers
Notes
Channel Labels

This capture was taken from a 2005 Toyota Hilux KUN26R with an early 1KD engine. The vehicle arrived in a no-start condition. After verifying that vehicles electrical and mechanical systems were all up to scratch, the injector current was monitored to assess injector operation. The current test showed that the current flow to the injectors was about half the expected value and was consistent across all four injectors. As there were no DTC's logged and after inspecting the wiring, it was decided that a new Injector Driver Unit (EDU) was the most likely cause.

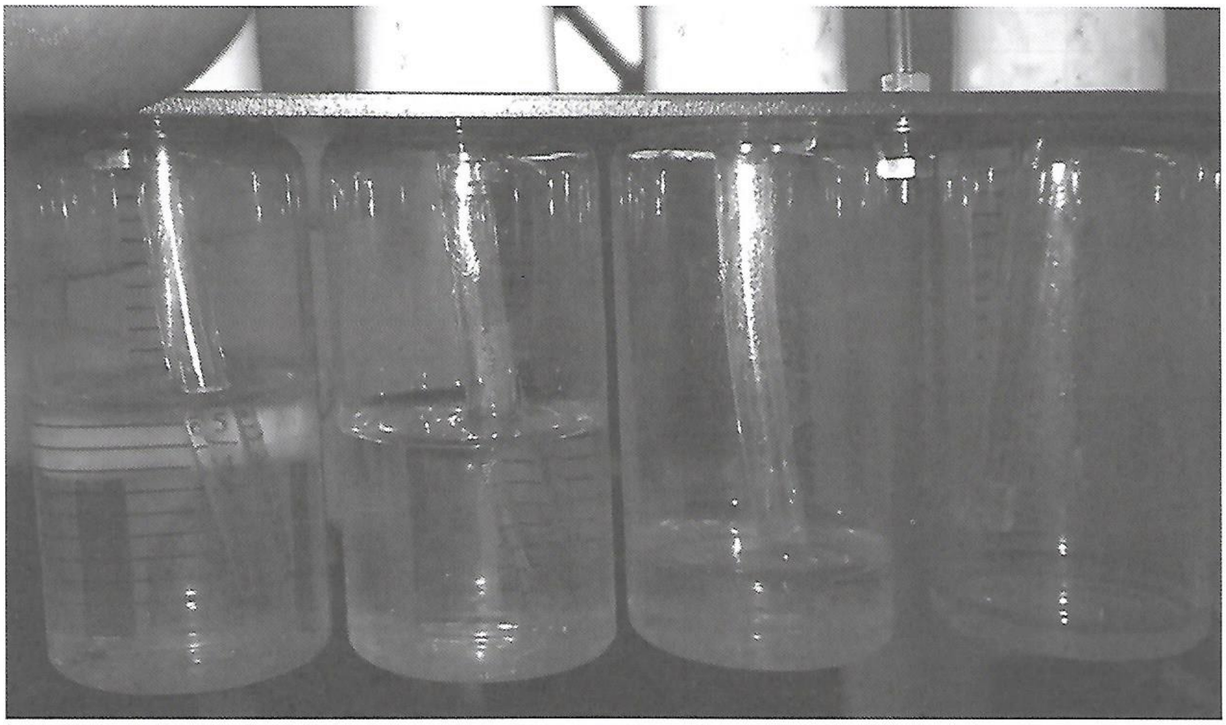

PicoScope 6 Automotive - [Toyota_Hilux_2005_Diesel_20191010-0001.psdata]
File Edit Views Measurements Tools Automotive Help
20 ms/div
1 MS
1 of 1
x 25.95
Off
5...20 A
DC
pico
85.7 µs
C: 16.16 A
Zoom Overview
-2.929
-2.158
-1.388
-0.617
0.154
0.925
1.695
2.466
3.237
4.008
4.779
ms
Stopped
Trigger Repeat
3.348 A
15 %
Measurements
Rulers
Notes
Channel Labels

After fitting the new EDU, the engine started first turn of the key and ran like it had never missed a beat.

FUEL INJECTOR CONTROL continued...

Back leakage method

Checking the injector actuation via back leakage testing can helpful in the absence of an oscilloscope. Cranking the engine for an extended period of time will be strenuous on the starter motor and battery. This method has been successfully used to diagnose a no start situation where two fuel injectors had completely failed and were not injecting any fuel and the vehicle (2009 Renault Kangoo) would not fire on the two remaining operational injectors.



NOTES

Section iv

Oscilloscope Tips

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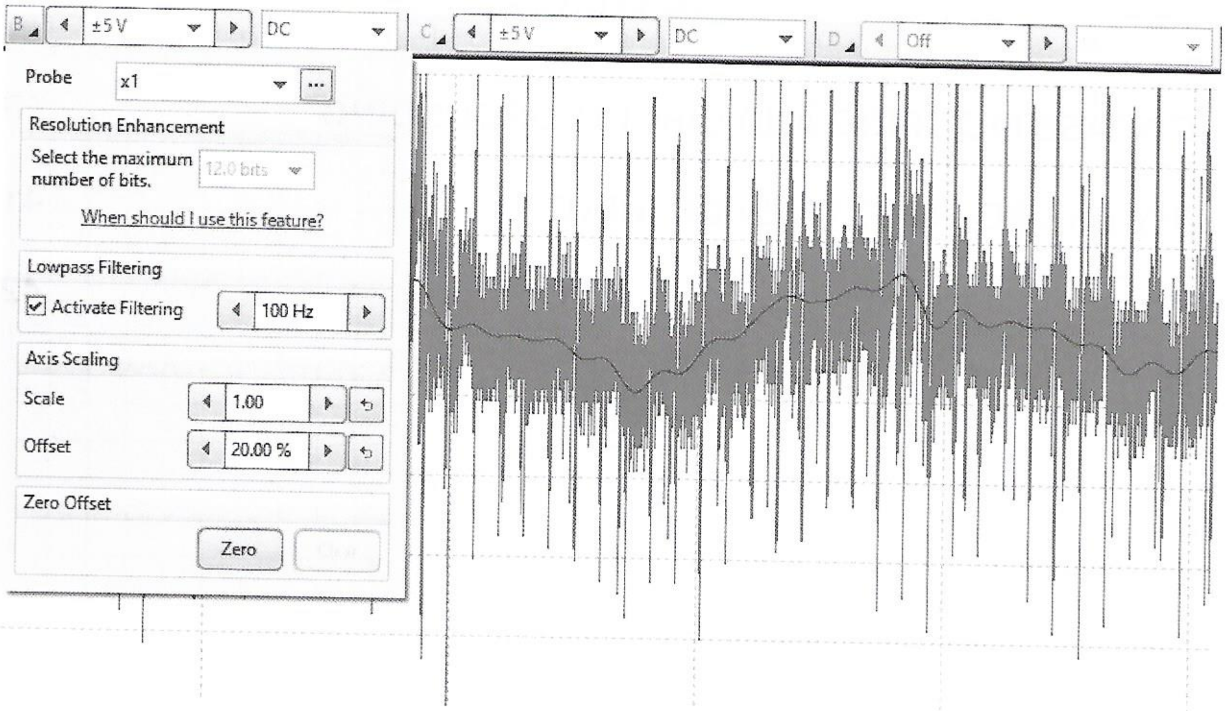
LOWPASS FILTERING AND CIRCUIT GROUNDING

Using a powerful oscilloscope is the best approach for most electronic diagnosis. Knowing what interference is normal and what is problematic is a tricky topic that can only be learned through experience, trial and error and sometimes a helpful tip. Some scope's, such as the PicoScope 6 Automotive, have a built-in filtering tool. The lowpass filter removes the high and low spikes [commonly known as noise] from the waveform, allowing the user to look past the interference and see the waveform values that the ECU is monitoring.



Probe: x1

Select the maximum number of bits. 12.0 bits

☑ Activate Filtering: 100 Hz

Scale: 1.00

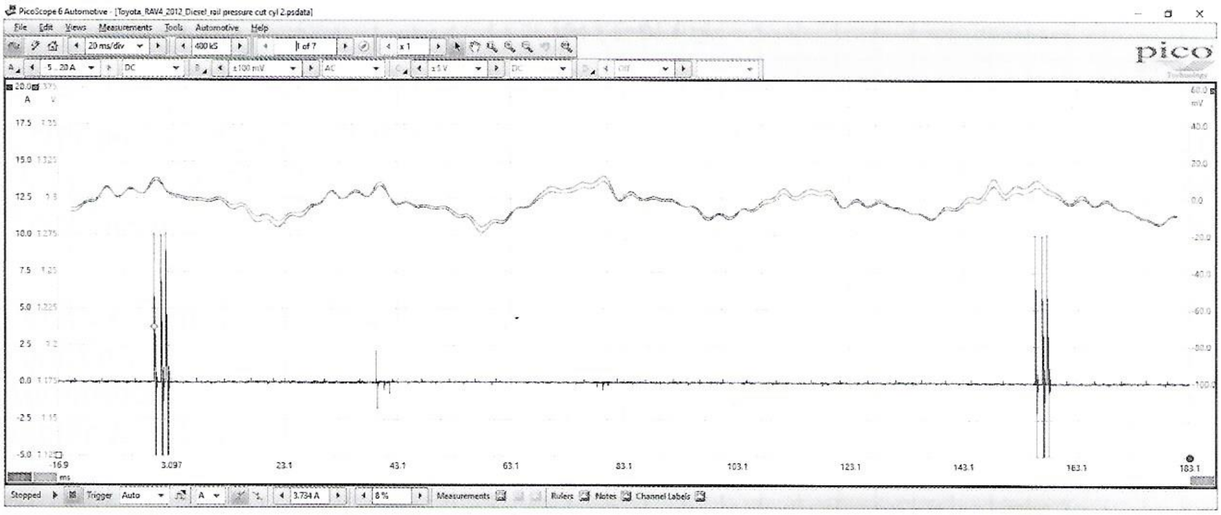
Offset: 20.00 %

However, the lowpass filter doesn't help the diagnostician to determine if the interference in the circuit is effecting the signal going to the ECU. To overcome this;

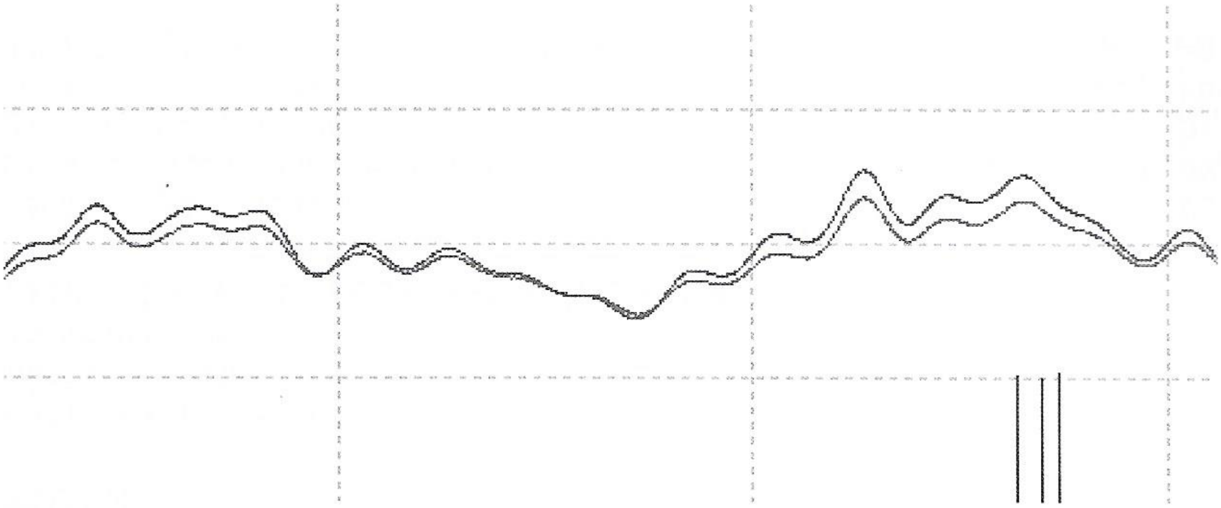
1. Turn OFF the lowpass filter
2. Measure the voltage drop between the negative battery terminal and the ground wire of the circuit you are testing while the circuit you are testing is operating under the same conditions where the interference was noted.
3. If the voltage drop is above 100mV then a ground issue to that circuit may be the cause of the interference and fault.
4. If the voltage drop is below 100mV shift the oscilloscopes reference ground from the negative battery terminal to the ground wire of the desired circuit. This procedure bypasses much of the interference, caused by the alternator, cooling fans, injector drivers, etc. Producing a waveform with similar results to using the lowpass filter. After all the ECU is only comparing the sensor signal to its reference.

WHY USE AC INPUT OVER DC INPUT?

Using AC inpu signal setting is not appropriate when you are trying to measure the actual voltage values because in AC mode the waveform is centred to 0 Volts. But with this test the desire is to compare the cyclical repetition of the waveform. By 'centring' the waveform at 0 Volts it allows the scope user to zoom in to the 100mV easily without the need to adjust the offset (in DC mode the waveform would disappear off the top of the screen).


PicoScope 6 Automotive - [Toyota_RAV4_2012_Diesel_rail pressure cut cyl 2.psdata]
File Edit Views Measurements Tools Automotive Help
20 ms/div
400 kS
1 of 7
x 1
pico
A 5..20 A DC
B ±100 mV AC
C ±5 V DC
D Off
A V
20.0 1.375
17.5 1.35
15.0 1.325
12.5 1.3
10.0 1.275
7.5 1.25
5.0 1.225
2.5 1.2
0.0 1.175
-2.5 1.15
-5.0 1.125
mV
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
-100.0
-16.9
3.097
23.1
43.1
63.1
83.1
103.1
123.1
143.1
163.1
183.1
ms
Stopped
Trigger Auto
A
3.734 A
8 %
Measurements
Rulers
Notes
Channel Labels

The upper waveform is in fact two wave forms. One is in DC mode that took a lot of adjustment and the other is in AC mode that was set up in a moment.



A zoom in on the waveform shows that the waveforms are ver similar. While the DC waveform is more accurate on the voltage scale. Because this test is purely visual and comparing the waveform during the 4 injection events. the AC waveform is accurate enough.

NOTES

Section v

Traditional CRD Injector testing methods

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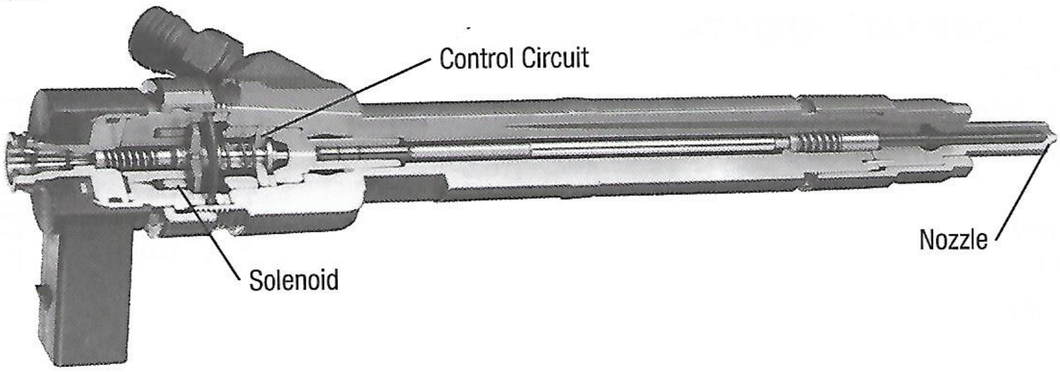
CRD INJECTOR TYPES

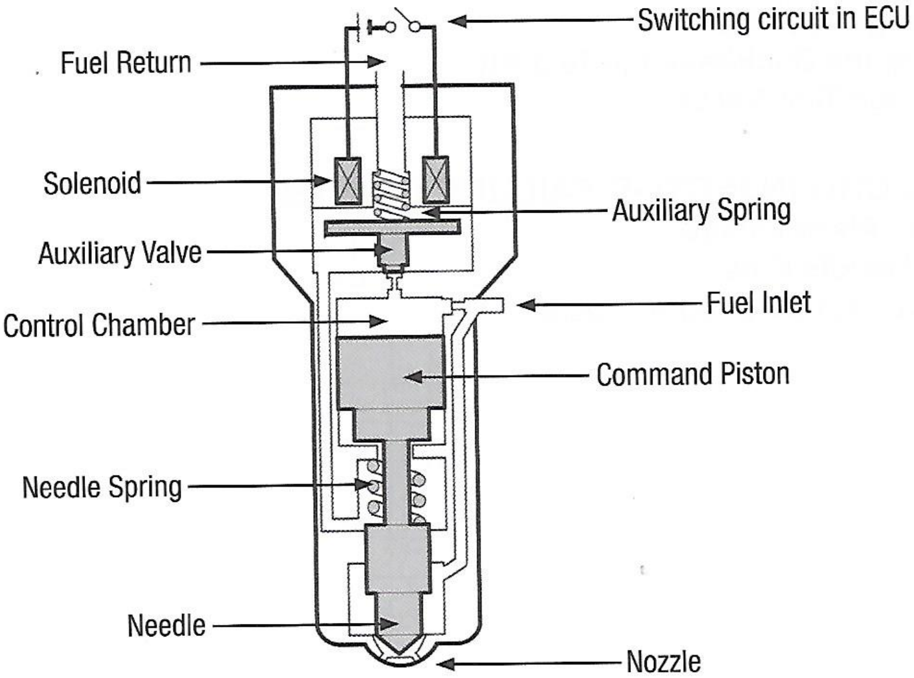
Common Rail Diesel Injectors can be actuated with either an Electro-solenoid or a Piezoelectric. It is also important to understand that due to the extremely high operating pressures, CRD Injectors are indirectly actuated.

Electro-solenoid

Electro-solenoid diesel fuel injectors were the typical fitment for CRD systems that were built to run at EURO III. In European countries and US CARB states, Piezoelectric Injectors were popular from EURO IV (or US equivalent) onwards. For Australia solenoid technology improved to such a level that often by the time the emission standard was introduced here the significantly cheaper and more reliable Solenoid type injectors were capable of meeting our needs. These injectors now perform well for up to 5 injections per cycle. Beyond this rate the Electro-solenoid diesel fuel injectors struggle to meet the operational demands of the highly efficient engines.


Control Circuit
Solenoid
Nozzle

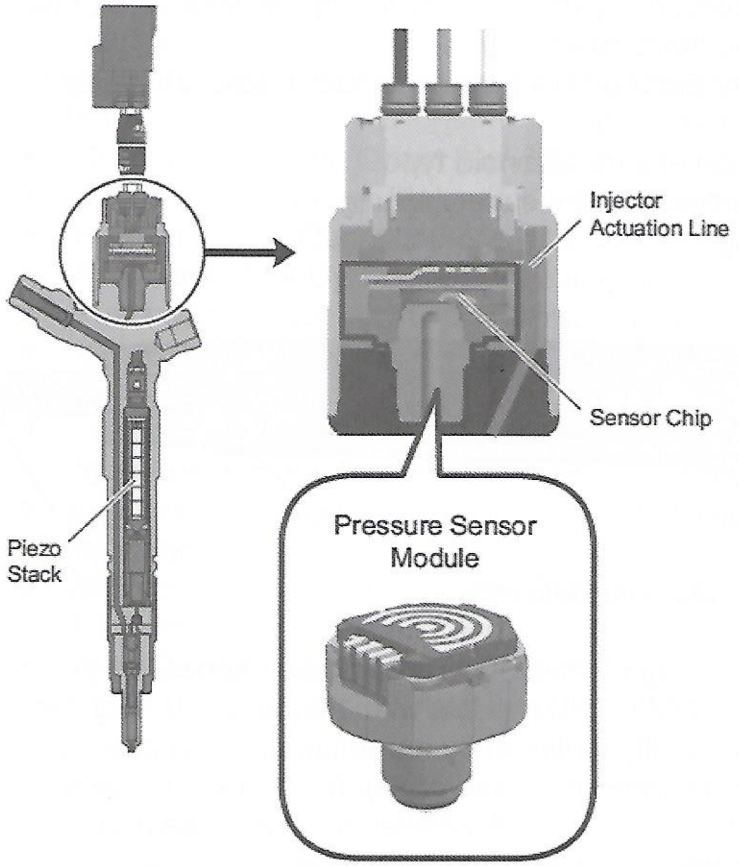
Typical Solenoid type CRD Injector

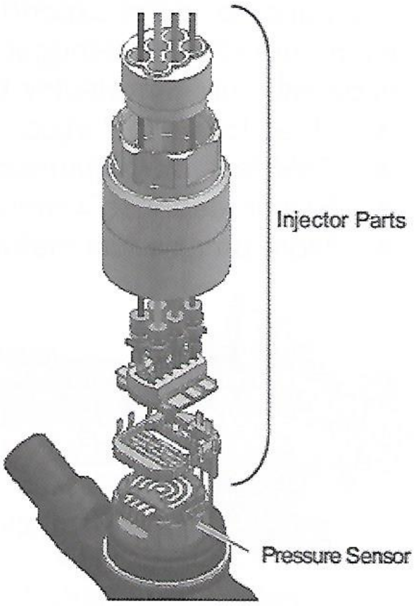

Switching circuit in ECU
Fuel Return
Solenoid
Auxiliary Spring
Auxiliary Valve
Fuel Inlet
Control Chamber
Command Piston
Needle Spring
Needle
Nozzle

Schematic diagram of Solenoid type CRD Injector

CRD INJECTOR TYPES continued...

These new fuel injectors have been designed and built by Denso. Coined intelligent-Accuracy Refinement Technology (i-ART), these injectors incorporate an integrated pressure sensor which monitors the changing pressures in the back leakage circuit allowing the ECM to monitor actual fuel injection quantity under ALL conditions!


Injector
Actuation Line
Sensor Chip
Piezo
Stack
Pressure Sensor
Module


Injector Parts
Pressure Sensor

The injectors have been fitted in all Brazilian delivered Hilux's with 1KD engines since April 2012. There is no clear indication of global release and how they perform in Brazil will determine their future use. It was suggested that the technology might be introduced globally when the EURO 6c legislation comes into force in the EU in 2017. However, there has been no evidence of these sensors in the Australian market as yet...

CRD INJECTOR TYPES continued...

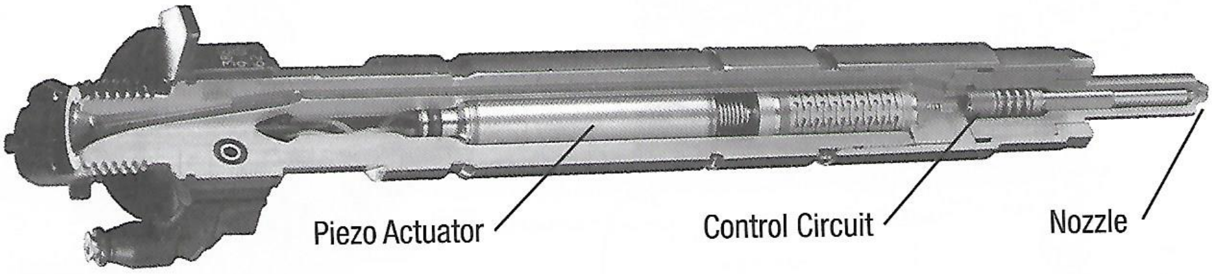
Piezoelectric

Piezoelectric diesel fuel injectors utilise a pack (approximately 400 discs) of Piezo Crystals. The nozzle design of a Piezo Electric is of the same principle design as Electro Solenoid diesel fuel injectors.

When excited by an electrical pulse from the Engine Control Module (ECM) the individual piezo discs expand, collectively this creates enough deflection to actuate the auxiliary valve and trigger the fuel injection.

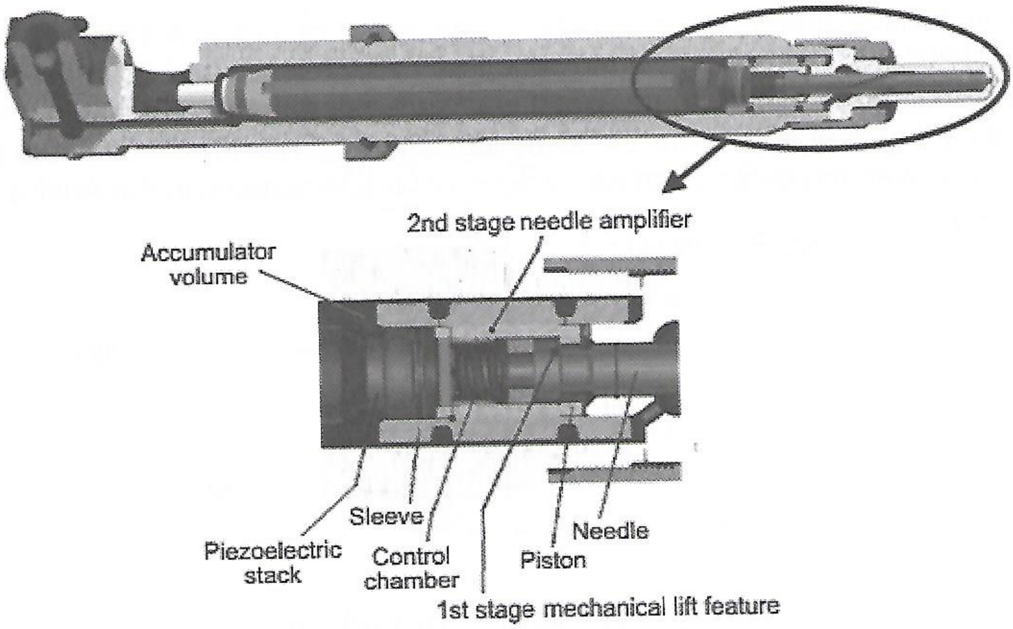
The benefits of Piezoelectric over Electro Solenoid diesel fuel injectors include:

- Used for up to 7 injection per cycle
- 75% less moving mass than electro solenoid type.
- Faster response = more efficient and cleaner running
- More precise fuel metering


Piezo Actuator
Control Circuit
Nozzle

Typical Piezo CRD Injector

In 2009 Delphi released a direct acting piezo CRD injector, it was adopted by Mercedes Benz on a variety of 2009MY CRD models with 1.8L and 2.1L engines. It was plagued by issues and eventually replaced by a traditional in-direct type injector. Fortunately, these injectors were only used on tightest emission specs (EURO V) and very few found their way into the Australian and New Zealand markets which were adhering to the EURO IV spec at the time.


2nd stage needle amplifier
Accumulator volume
Sleeve
Needle
Piezoelectric stack
Control chamber
Piston
1st stage mechanical lift feature

Delphi Direct Acting CRD Injector

FUEL ADAPTATION DATA

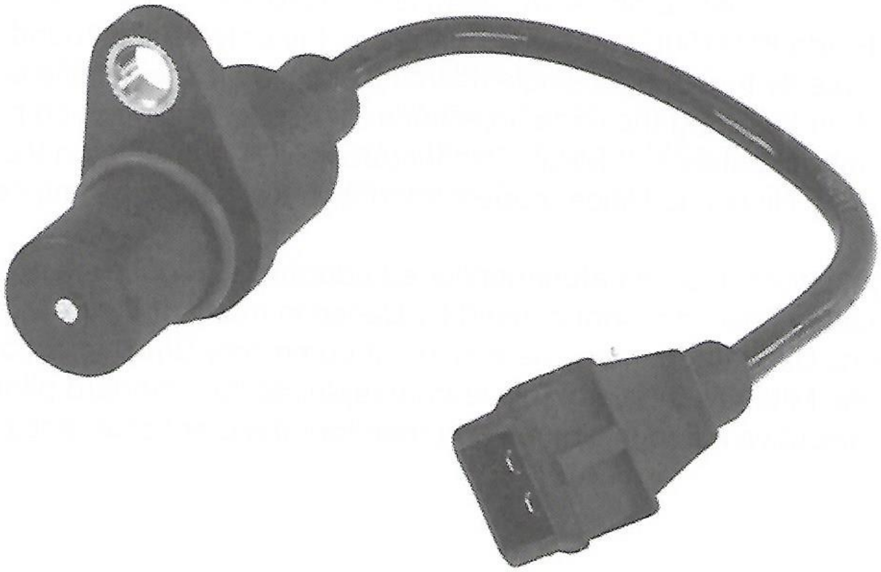
The fuel adaptation tables are used to alter the fuel injection quantities in order to achieve smoother engine operation. The scope and limitations of these adaptations will be discussed on the following pages.

While most manufacturers provide these values in the Scan Tool Data, there are a few that don't. The other impacting factor is whether the maker/programmer of your aftermarket scan tool has programmed all of the parameters for any specific vehicle. The terms (names) used by manufacturers for this parameter varies, here are a few that are known:

- Cylinder Balancing Offset (Land Rover with Siemens VDO)
- Cylinder Contribution/Balance (Ford with Siemens VDO)
- Fuel Balancing Quantity (Ford with Siemens VDO)
- Fuel Control for Cylinder Balance (Denso)
- Fuel Injection Quantity Offset (Nissan with Denso)
- Idle Stabilisation (VW AG with Bosch)
- Injection Amount Correction (Citroen, Holden, Mazda with Denso)
- Injection Feedback Value (Toyota with Denso)
- Injection Quantity Correction (Toyota, Mitsubishi, Subaru with Denso)
- Injection Quantity Deviation (VW AG with Bosch)
- Injection Quantity Learning (Nissan with Denso)
- Microinjection Quantity Learning (Toyota, Mazda, Subaru with Denso)
- Perform Pilot Correction Learn (Ford with Denso)
- Pilot Quantity Learning (Toyota with Denso)
- Small Injection Quantity Learning (Mitsubishi with Denso)

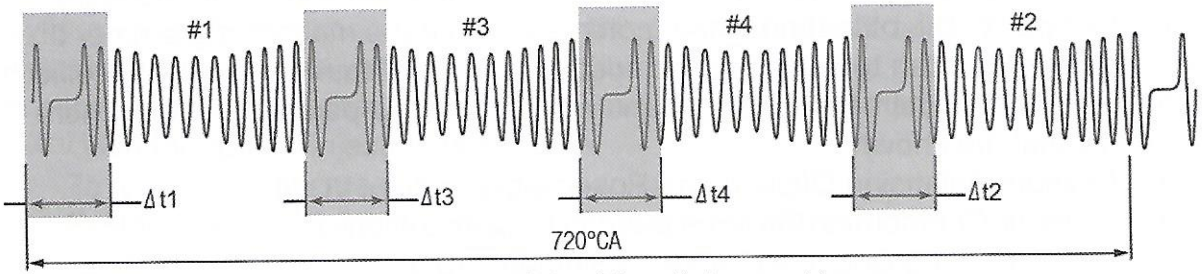
Function

All of these different terms relate to the same single principle, to smooth out idle instability, noise and emissions! What's more they all identify the idle instability with the same sensor...



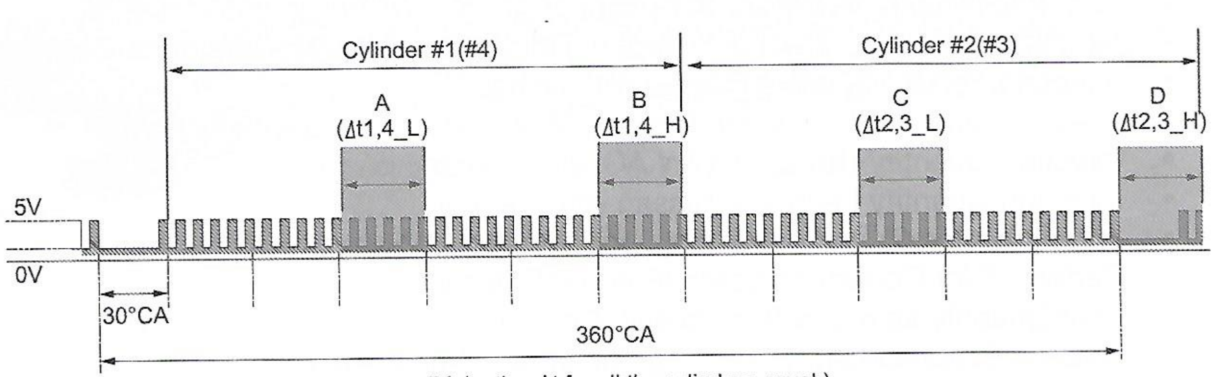
FUEL ADAPTATION DATA continued...

The Crankshaft Position Sensor (or whatever you might prefer to call it) is monitored for deviations. The ECU is programmed to compare the time taken for the crankshaft to rotate a specific number of degrees after combustion. The same sample window is monitored for each cylinder.



(Make the Δt for all the cylinders equal.)

Example of sample range (in grey) for engine using an inductive type Crankshaft Position Sensor



(Make the Δt for all the cylinders equal.)

Example of sample range (in grey) for engine using a hall effect type Crankshaft Position Sensor

In order to measure the rotational time, it is essential to have the engine operating in a controlled environment where engine load variations will not affect the sample. For this reason all but one of the 21 system combinations mentioned on the previous page carry out the test with the engine at idle.

The Toyota Prado KDJ150R with a 1KD engine is the only vehicle found that takes its sample by triggering a single microinjection while the vehicle is in fuel cut deceleration. Allowing the micro injections to be checked at much higher rail pressures (approximately 100 MPa). This feature is NOT available on the previous KDJ120R or any Hilux and Hiace models fitted with the KD series engines.

Another slight variation of the aforementioned adaptation processes is the Micro-injection Quantity Learning Control used by Denso in many of their systems, from 2007 onwards. Used under many names (most commonly Small Injection Quantity Learning in the Mitsubishi Pajero) this feature replaces the standard pilot injection with five consecutive micro injections and monitors the crankshaft acceleration at idle.

FUEL ADAPTATION DATA continued...

Adaptation

All of these adaptation processors are used to adjust the injection pulse width (on-time) to ensure that all cylinders are creating the same amount of power output (torque). What is not often understood is that the fuel adaptation ONLY AFFECTS IDLE. They have no affect on fuel injection quantities as soon as the engine is off idle.

It is important to remember that faults outside of the fuel injection systems can cause variations in the fuel adaptation tables. The faults include:

- Engine mechanical faults
- Any engine control faults
- Fuel delivery faults (air leaks)
- Excessive/Insufficient fuel return pressure

Another shortcoming of this system is that it only monitors the injectors operation at idle rail pressure (typically 30-40MPa). This means that the injector faults that are accentuated by pressure are either missed or inadequately adapted.

To summarise the adaptation process;
It is designed to monitor engine idle for inconsistencies and adjust the injector pulse width to obtain the best idle quality. It is used by manufacturers as a guide towards injector wear and failure but it cannot rule out influences from outside of the control system. Lastly, adaptation has zero effect above idle.

Values and Parameters

There are a few ways in which manufacturers display the adaptation values and their acceptable deviations. Adaptation values can be in reference to:

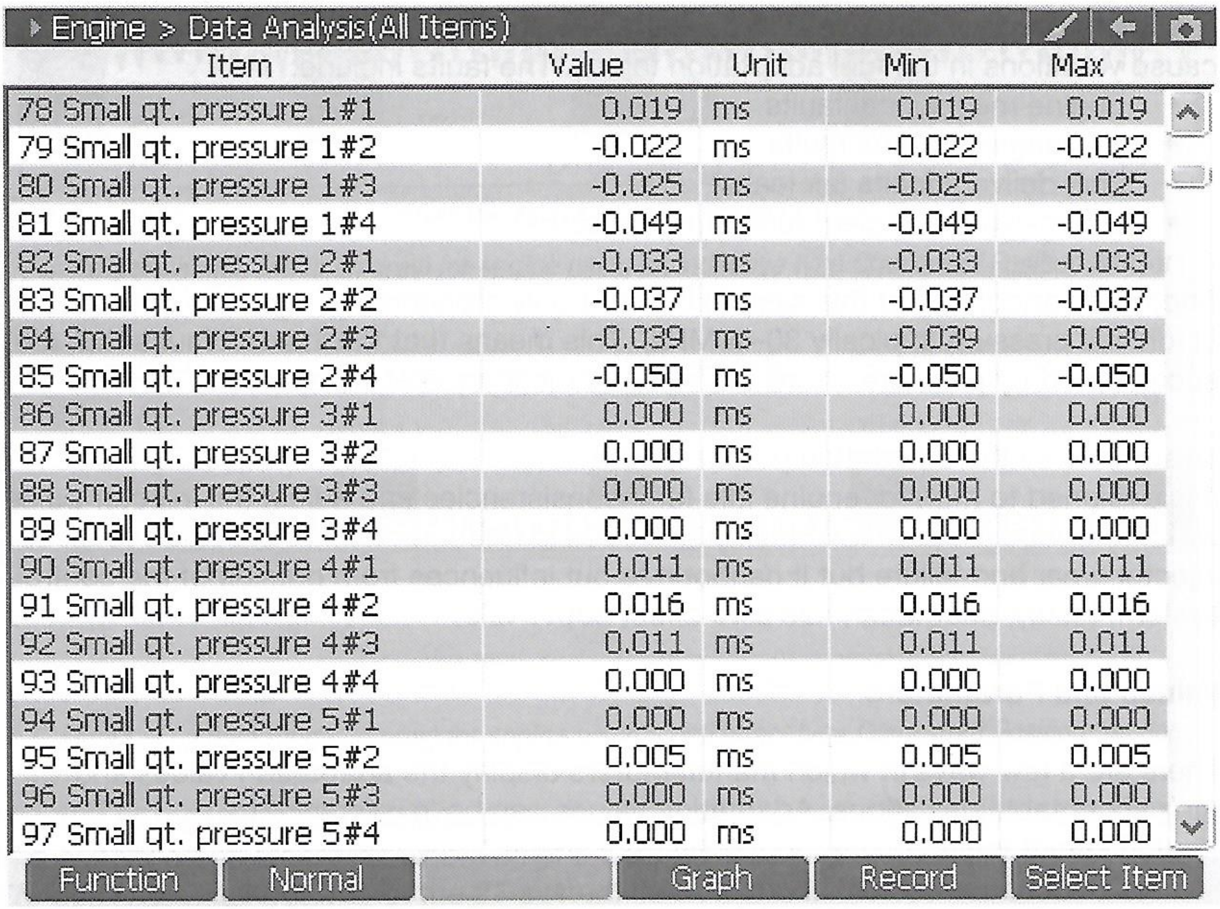
- Time
- Quantity
- Weight
- Arbitrary (no direct relationship between value and action)

Note: *REMEMBER, that regardless of the unit value, ALL systems monitor the crankshaft to identify irregularities and adjust the injector pulse width to make variations!*

FUEL ADAPTATION DATA continued...

Time

Using time as the adaptation value is the most relevant to the actual process being conducted by the ECM, because any adjustments are made by increasing or decreasing the pulse width (on-time). Surprisingly this seems to be one of the least used values. When time is used as the adaptation value, the value is displayed in either milliseconds (ms) or microseconds (µs).



Item	Value	Unit	Min	Max
78 Small qt. pressure 1#1	0.019	ms	0.019	0.019
79 Small qt. pressure 1#2	-0.022	ms	-0.022	-0.022
80 Small qt. pressure 1#3	-0.025	ms	-0.025	-0.025
81 Small qt. pressure 1#4	-0.049	ms	-0.049	-0.049
82 Small qt. pressure 2#1	-0.033	ms	-0.033	-0.033
83 Small qt. pressure 2#2	-0.037	ms	-0.037	-0.037
84 Small qt. pressure 2#3	-0.039	ms	-0.039	-0.039
85 Small qt. pressure 2#4	-0.050	ms	-0.050	-0.050
86 Small qt. pressure 3#1	0.000	ms	0.000	0.000
87 Small qt. pressure 3#2	0.000	ms	0.000	0.000
88 Small qt. pressure 3#3	0.000	ms	0.000	0.000
89 Small qt. pressure 3#4	0.000	ms	0.000	0.000
90 Small qt. pressure 4#1	0.011	ms	0.011	0.011
91 Small qt. pressure 4#2	0.016	ms	0.016	0.016
92 Small qt. pressure 4#3	0.011	ms	0.011	0.011
93 Small qt. pressure 4#4	0.000	ms	0.000	0.000
94 Small qt. pressure 5#1	0.000	ms	0.000	0.000
95 Small qt. pressure 5#2	0.005	ms	0.005	0.005
96 Small qt. pressure 5#3	0.000	ms	0.000	0.000
97 Small qt. pressure 5#4	0.000	ms	0.000	0.000

Small Quantity Injections adaptation values from a 2010 Mitsubishi Pajero 4M41 in milliseconds to 3 decimal places (0.001ms = 1µs).

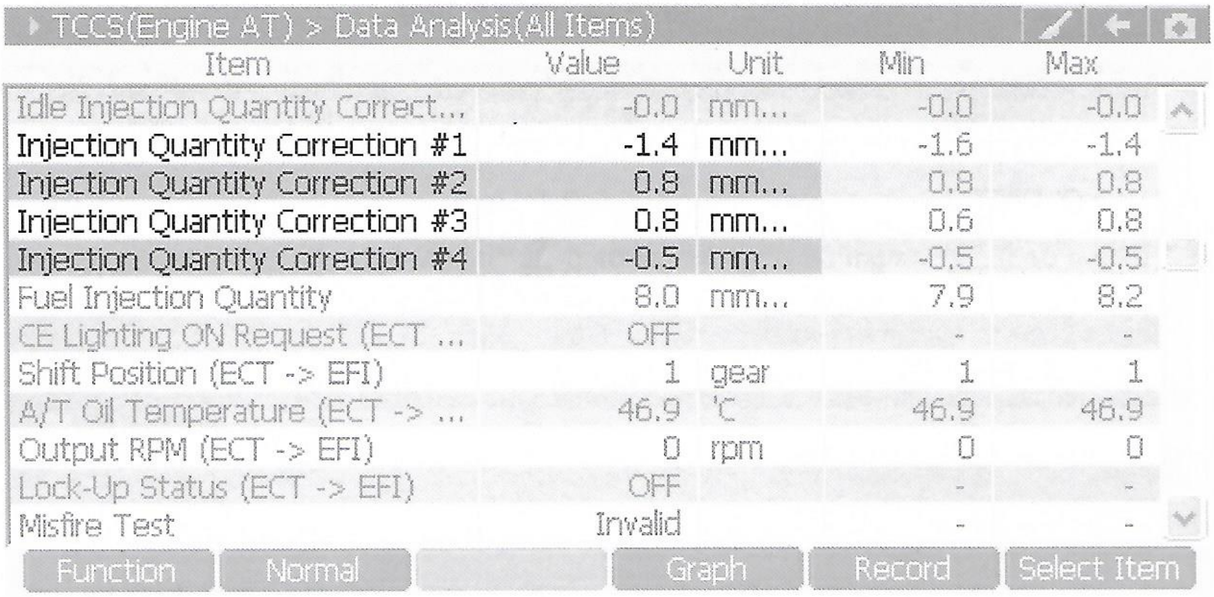
Note: *Mitsubishi do not use the small quantity injection adaption for diagnostic purposes nor do they provide a normal operating range!*

FUEL ADAPTATION DATA continued...

Quantity
The adaptation value can also be offered as an inferred measurement of the quantity of the fuel sample delivered at each power stroke. When quantity is used as the adaptation value, the value is displayed in cubic millimetres per stroke (mm3/st). This is the preferred value used by most Denso systems.

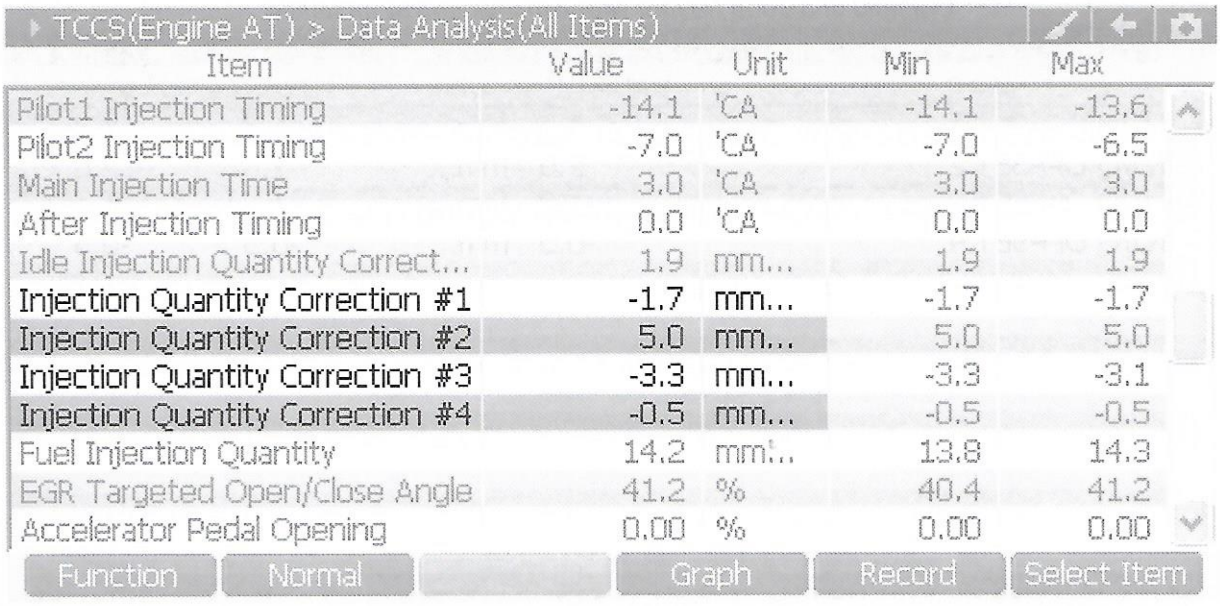
Toyota 1KD - Parameters
Toyota states that:

- Normal operating range is 0 ± 3.0mm^3/st @ idle
- Full operating range is 0 ± 4.9mm^3/st @ idle
- A value of ± 5.0mm^3/st @ idle indicates a failed injector


TCCS(Engine AT) > Data Analysis(All Items)

Item	Value	Unit	Min	Max
Idle Injection Quantity Correct...	-0.0	mm...	-0.0	-0.0
Injection Quantity Correction #1	-1.4	mm...	-1.6	-1.4
Injection Quantity Correction #2	0.8	mm...	0.8	0.8
Injection Quantity Correction #3	0.8	mm...	0.6	0.8
Injection Quantity Correction #4	-0.5	mm...	-0.5	-0.5
Fuel Injection Quantity	8.0	mm...	7.9	8.2
CE Lighting ON Request (ECT ...	OFF		-	-
Shift Position (ECT -> EFI)	1	gear	1	1
A/T Oil Temperature (ECT -> ...	46.9	'C	46.9	46.9
Output RPM (ECT -> EFI)	0	rpm	0	0
Lock-Up Status (ECT -> EFI)	OFF		-	-
Misfire Test	Invalid		-	-

Example of a 2009 Hilux operating within normal specifications.


TCCS(Engine AT) > Data Analysis(All Items)

Item	Value	Unit	Min	Max
Pilot1 Injection Timing	-14.1	'CA	-14.1	-13.6
Pilot2 Injection Timing	-7.0	'CA	-7.0	-6.5
Main Injection Time	3.0	'CA	3.0	3.0
After Injection Timing	0.0	'CA	0.0	0.0
Idle Injection Quantity Correct...	1.9	mm...	1.9	1.9
Injection Quantity Correction #1	-1.7	mm...	-1.7	-1.7
Injection Quantity Correction #2	5.0	mm...	5.0	5.0
Injection Quantity Correction #3	-3.3	mm...	-3.3	-3.1
Injection Quantity Correction #4	-0.5	mm...	-0.5	-0.5
Fuel Injection Quantity	14.2	mm...	13.8	14.3
EGR Targeted Open/Close Angle	41.2	%	40.4	41.2
Accelerator Pedal Opening	0.00	%	0.00	0.00

Example of a 2005 Hilux with one failed injector and another outside of normal range.

FUEL ADAPTATION DATA continued...

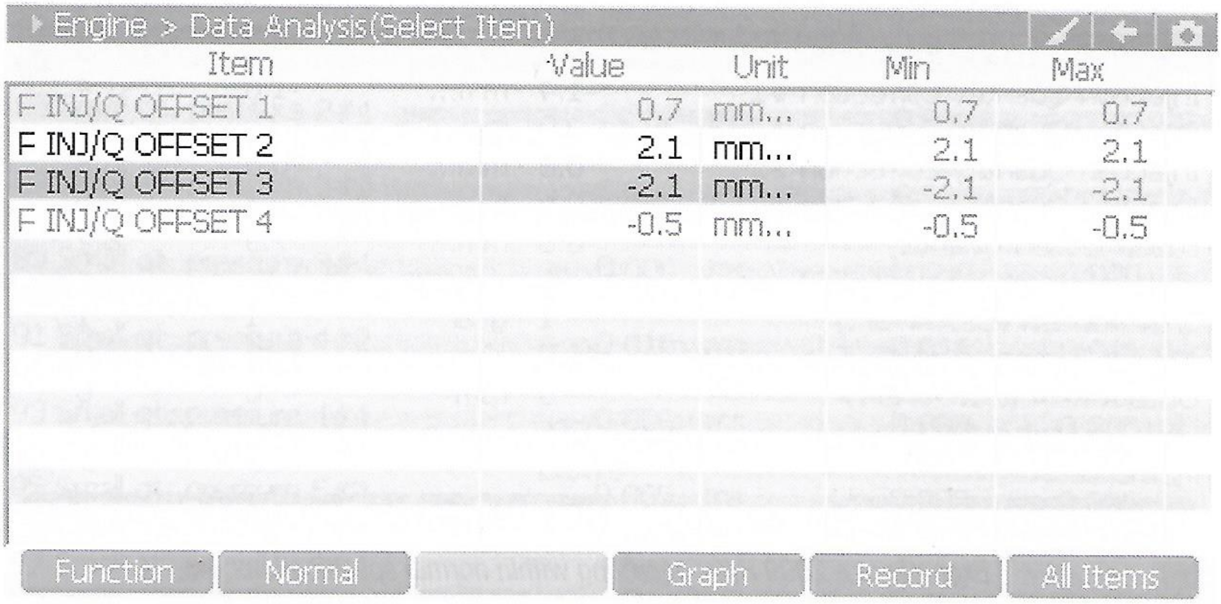
Nissan YD25 - Parameters

Nissan states that:

- Normal operating range is 0 ± 2.1mm^3/st @ idle
- If an injector reads 2.1mm^3/st it should be replaced
- If the vehicle has poor idle, noise or performance issues and one injector is found to be in the opposite spectrum, the odd injector should be replaced

Caution: *Nissan YD25 engines will display a Fuel Injection Quantity Offset of '0.0' until the following are met:*

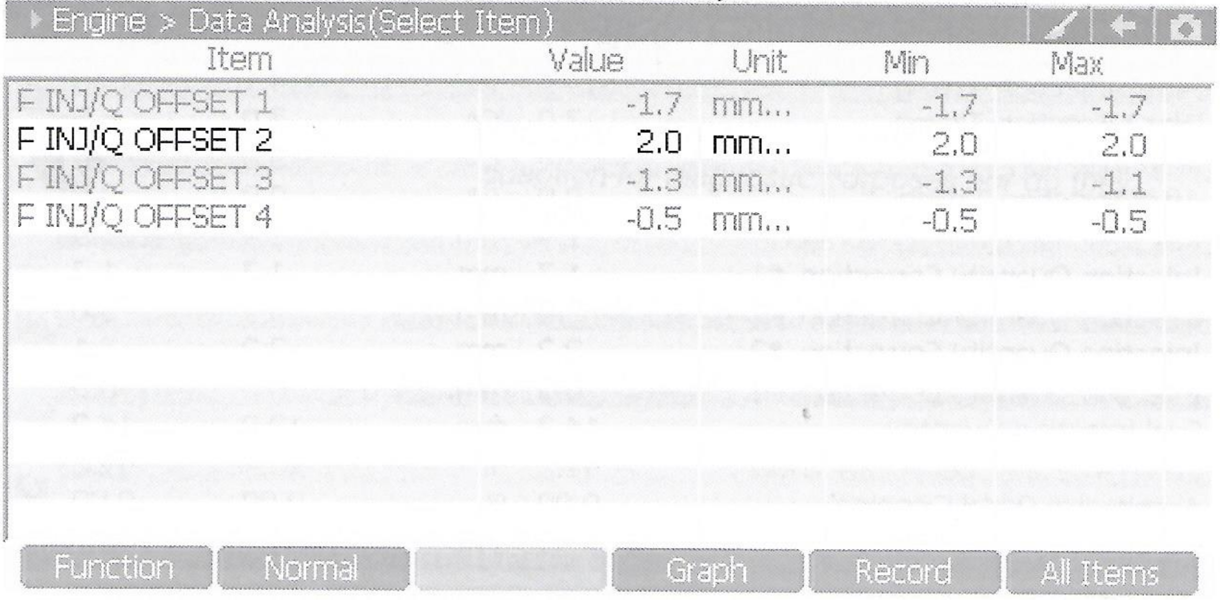
- No DTC's set
- Coolant temp above 60°C
- Engine idling
- Shift lever in Neutral



Engine > Data Analysis(Select Item)

Item	Value	Unit	Min	Max
F INJ/Q OFFSET 1	0.7	mm...	0.7	0.7
F INJ/Q OFFSET 2	2.1	mm...	2.1	2.1
F INJ/Q OFFSET 3	-2.1	mm...	-2.1	-2.1
F INJ/Q OFFSET 4	-0.5	mm...	-0.5	-0.5

Example of a 2009 Navara with two injectors at threshold.



Engine > Data Analysis(Select Item)

Item	Value	Unit	Min	Max
F INJ/Q OFFSET 1	-1.7	mm...	-1.7	-1.7
F INJ/Q OFFSET 2	2.0	mm...	2.0	2.0
F INJ/Q OFFSET 3	-1.3	mm...	-1.3	-1.1
F INJ/Q OFFSET 4	-0.5	mm...	-0.5	-0.5

Example of a 2009 Navara with one injector on the opposite spectrum.

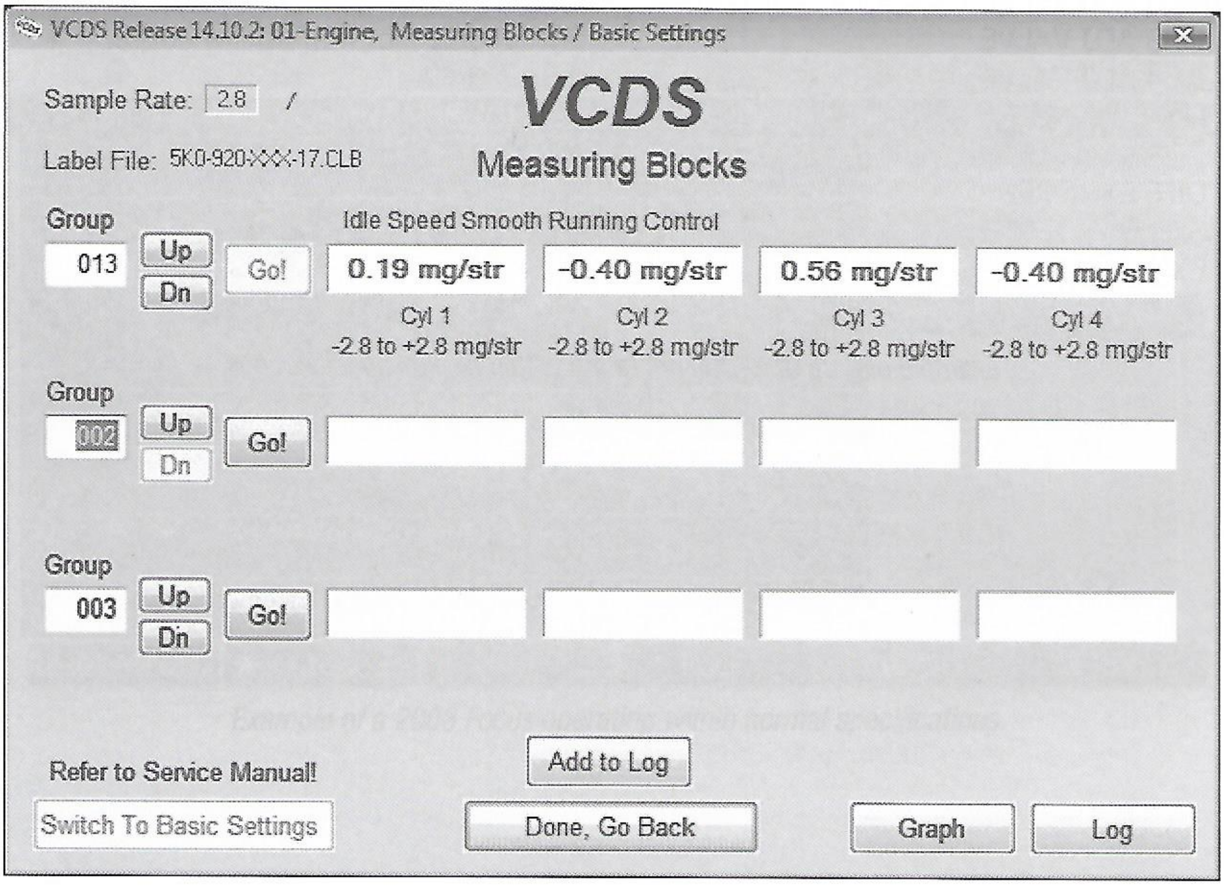
FUEL ADAPTATION DATA continued...

Weight
Weight is another unit of measurement used to display the fuel adaptation values. There are two main ways the value is displayed, either milligrams per stroke (mg/st) or grams per kilowatt hour (g/kWh).

Note: *Some French derived vehicles (including some Nissan's) use mg/Cp, Coup (Cp) translates to stroke!*

VW 1.6L TDI - Parameters

- Normal operating range is 0 ± 2.8mg/st @ idle



VCDS Release 14.10.2: 01-Engine, Measuring Blocks / Basic Settings

Sample Rate: 2.8

Label File: 5K0-920-XXX-17.CLB

Group 013 — Idle Speed Smooth Running Control

Cyl 1	Cyl 2	Cyl 3	Cyl 4
0.19 mg/str	-0.40 mg/str	0.56 mg/str	-0.40 mg/str
-2.8 to +2.8 mg/str	-2.8 to +2.8 mg/str	-2.8 to +2.8 mg/str	-2.8 to +2.8 mg/str

Group 002

Group 003

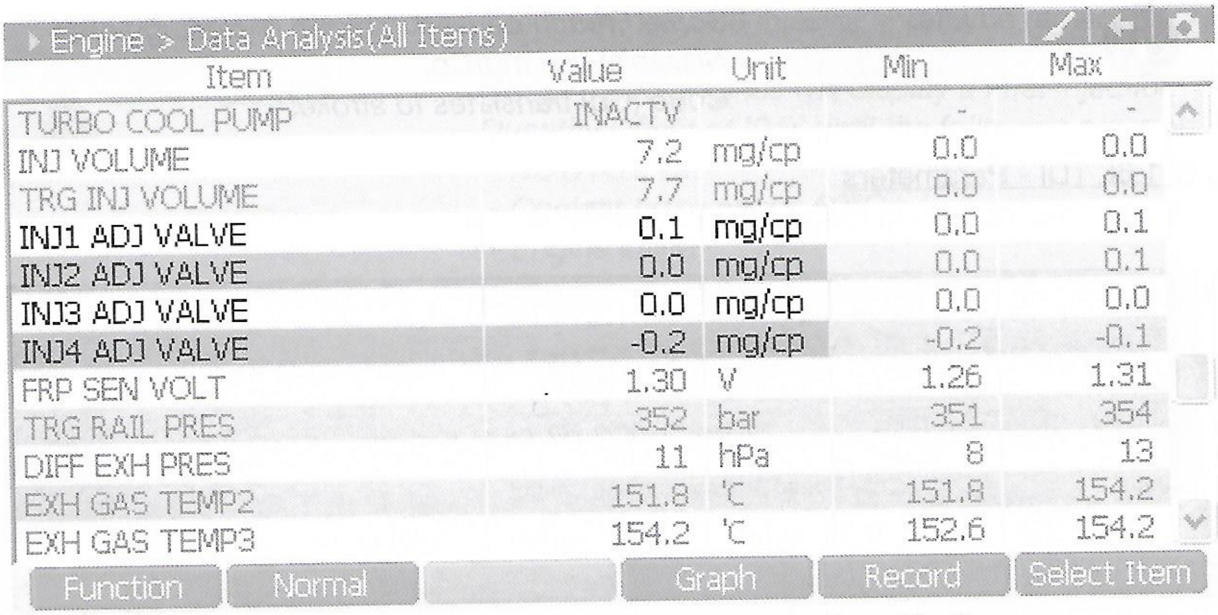
Refer to Service Manual!

Example of a 2010 Golf operating within normal specifications.

FUEL ADAPTATION DATA continued...

Nissan 2.0L M9R - Parameters

- Normal operating range is not provided by the manufacturer
- DTC's: P0263 (CYL#1), P0266 (CYL#2), P0269 (CYL#3) & P0272 (CYL#4) will be set by the ECM if the range is exceeded



Item	Value	Unit	Min	Max
TURBO COOL PUMP	INACTV		-	-
INJ VOLUME	7.2	mg/cp	0.0	0.0
TRG INJ VOLUME	7.7	mg/cp	0.0	0.0
INJ1 ADJ VALVE	0.1	mg/cp	0.0	0.1
INJ2 ADJ VALVE	0.0	mg/cp	0.0	0.1
INJ3 ADJ VALVE	0.0	mg/cp	0.0	0.0
INJ4 ADJ VALVE	-0.2	mg/cp	-0.2	-0.1
FRP SEN VOLT	1.30	V	1.26	1.31
TRG RAIL PRES	352	bar	351	354
DIFF EXH PRES	11	hPa	8	13
EXH GAS TEMP2	151.8	℃	151.8	154.2
EXH GAS TEMP3	154.2	℃	152.6	154.2

Example of a 2010 X-Trail operating within normal specifications.

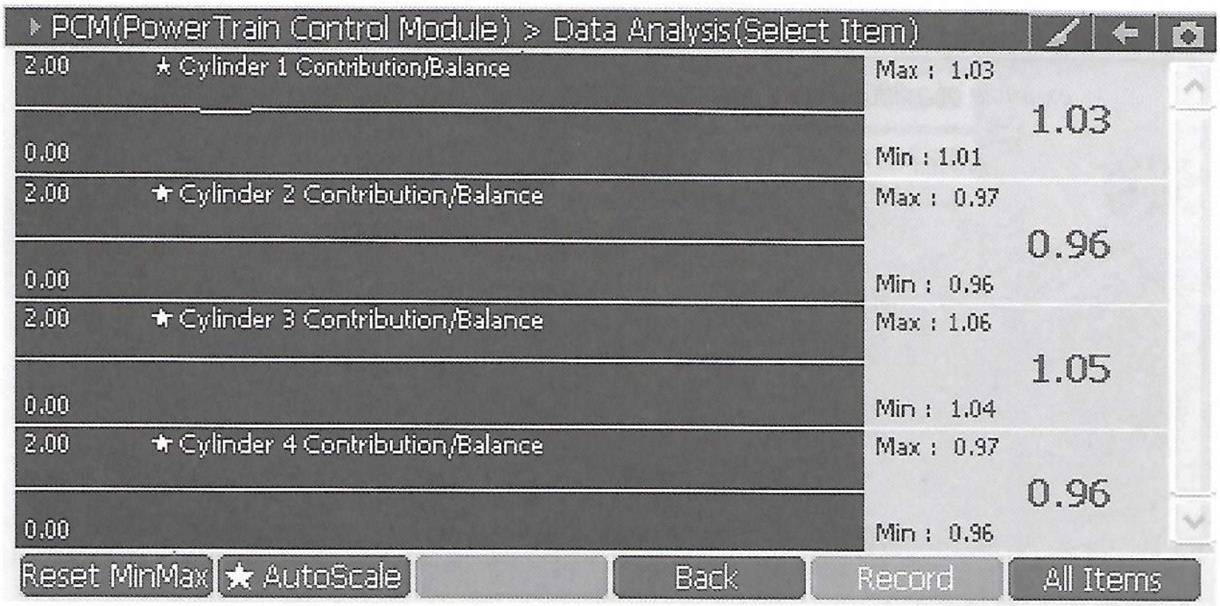
FUEL ADAPTATION DATA continued...

Arbitrary
Another method used to display the adaptation values is to pick a value and then adjust the value either side of the optimal value. The value has no direct relevance with the injection quantity.

This method has been popular with vehicles using the Continental/Siemems/VDO common rail control systems. Two examples follow:

Ford 2.0L Duratorq - Parameters

- Cylinder Contribution/Balance is on a 0 to 2 scale
- 1 represents the baseline (it might help to think of it as 100%)
- Ford states that: Normal operating range is 0 ± 0.25
- Values will default to 1 above idle



2.00 ★ Cylinder 1 Contribution/Balance 0.00 — Max : 1.03 — 1.03 — Min : 1.01

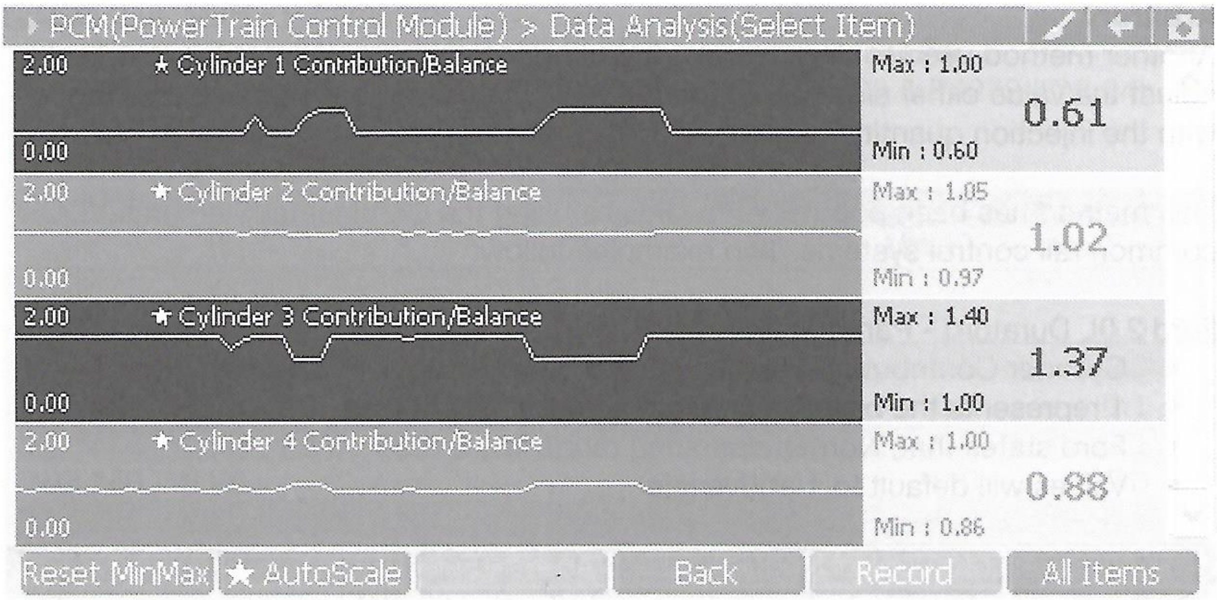
2.00 ★ Cylinder 2 Contribution/Balance 0.00 — Max : 0.97 — 0.96 — Min : 0.96

2.00 ★ Cylinder 3 Contribution/Balance 0.00 — Max : 1.06 — 1.05 — Min : 1.04

2.00 ★ Cylinder 4 Contribution/Balance 0.00 — Max : 0.97 — 0.96 — Min : 0.96

Example of a 2008 Focus operating within normal specifications.

FUEL ADAPTATION DATA continued...



PCM(PowerTrain Control Module) > Data Analysis(Select Item)

★ Cylinder 1 Contribution/Balance
Max : 1.00
0.61
Min : 0.60

★ Cylinder 2 Contribution/Balance
Max : 1.05
1.02
Min : 0.97

★ Cylinder 3 Contribution/Balance
Max : 1.40
1.37
Min : 1.00

★ Cylinder 4 Contribution/Balance
Max : 1.00
0.88
Min : 0.86

Example of a 2008 Focus operating within two cylinders out of specifications.

Note:

It is most likely that the cylinders with the high offsets are the cause of the fault and the low values are trying to compensate.

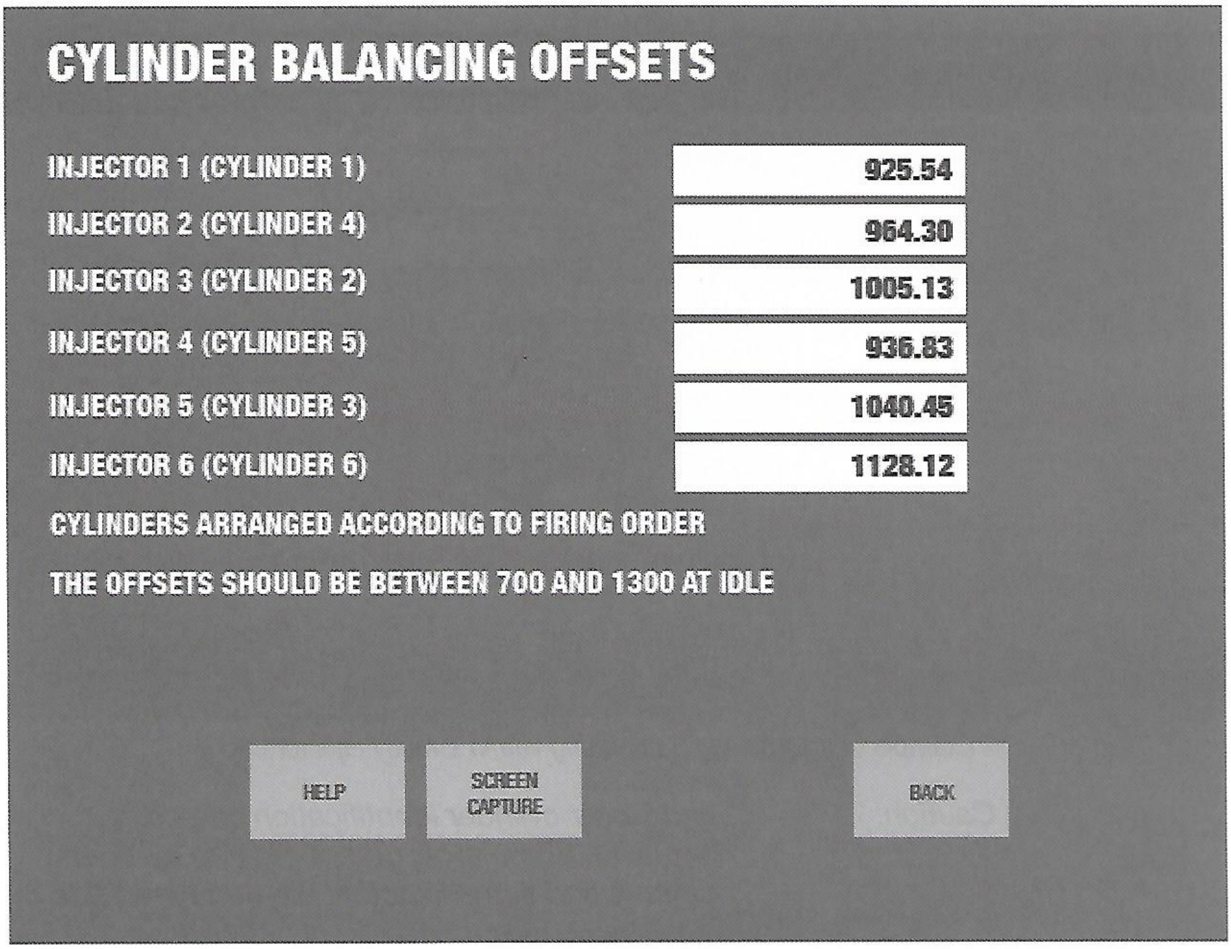
HOWEVER, this is not always the case...

ALWAYS carry out full diagnosis before replacing parts!

FUEL ADAPTATION DATA continued...

Land Rover TDV6 - Parameters

- Cylinder Contribution/Balance is on a 0 to 2000 scale
- 1000 represents the baseline (it might help to think of it as 100%)
- Land Rover states that: Normal operating range is 700 to 1300
- Values will default to 1000 above idle



CYLINDER BALANCING OFFSETS

INJECTOR 1 (CYLINDER 1)	925.54
INJECTOR 2 (CYLINDER 4)	964.30
INJECTOR 3 (CYLINDER 2)	1005.13
INJECTOR 4 (CYLINDER 5)	936.83
INJECTOR 5 (CYLINDER 3)	1040.45
INJECTOR 6 (CYLINDER 6)	1128.12

CYLINDERS ARRANGED ACCORDING TO FIRING ORDER

THE OFFSETS SHOULD BE BETWEEN 700 AND 1300 AT IDLE

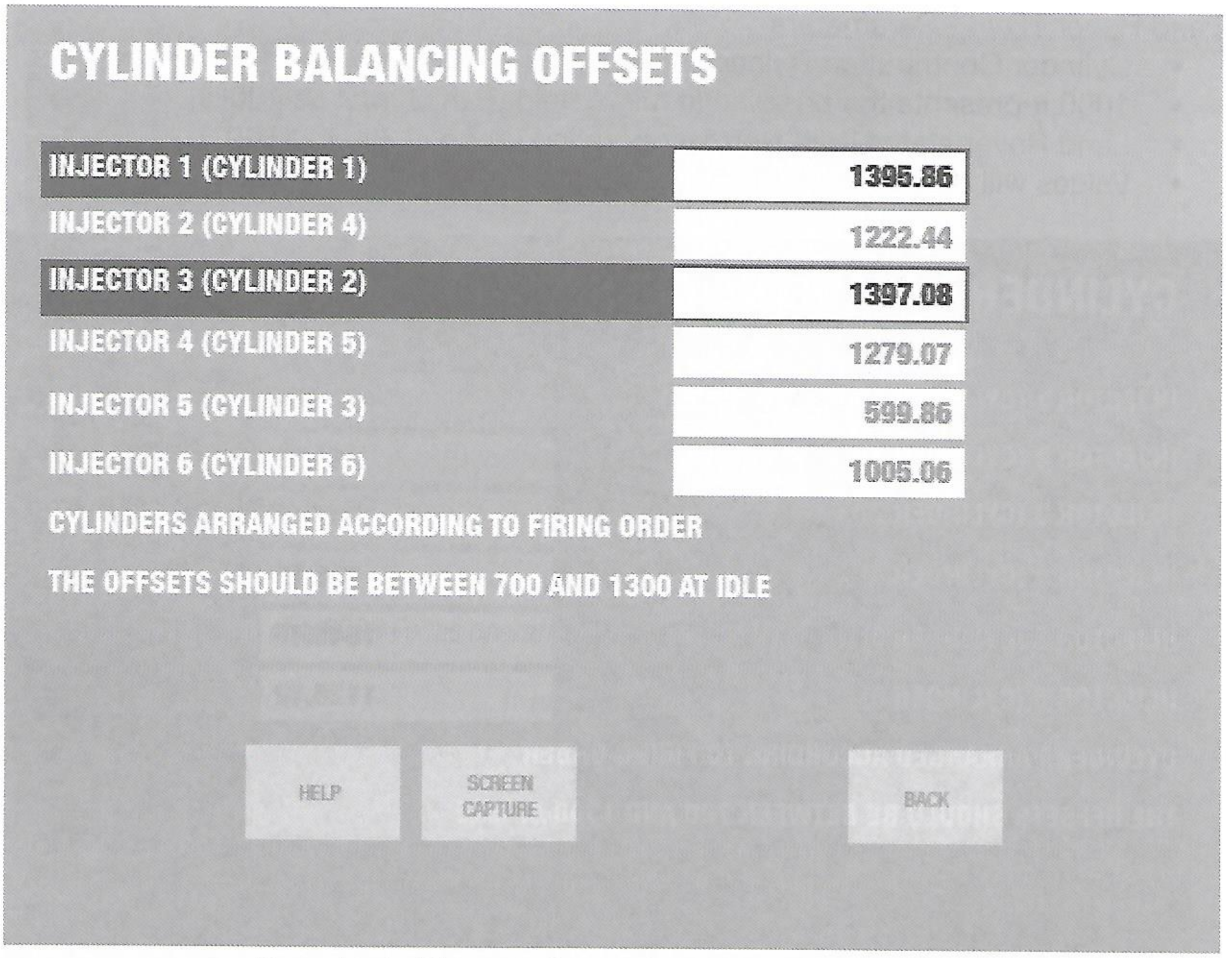
Example of a Discovery 3 operating within normal specifications

Note: *It is most likely that the cylinders with the high offsets are the cause of the fault and the low values are trying to compensate.*

HOWEVER, this is not always the case...

ALWAYS carry out full diagnosis before replacing parts!

FUEL ADAPTATION DATA continued...



CYLINDER BALANCING OFFSETS

INJECTOR 1 (CYLINDER 1)	1395.86
INJECTOR 2 (CYLINDER 4)	1222.44
INJECTOR 3 (CYLINDER 2)	1397.08
INJECTOR 4 (CYLINDER 5)	1279.07
INJECTOR 5 (CYLINDER 3)	599.86
INJECTOR 6 (CYLINDER 6)	1005.06

CYLINDERS ARRANGED ACCORDING TO FIRING ORDER

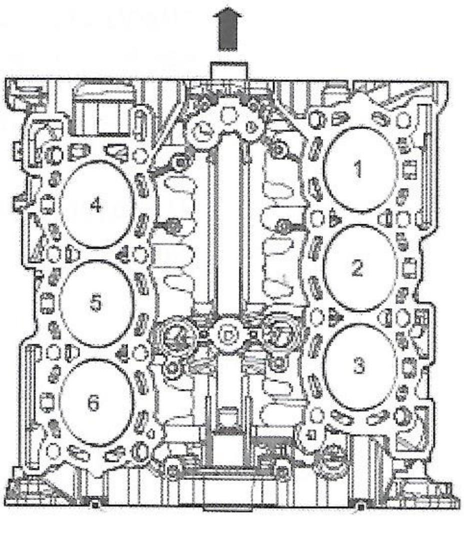
THE OFFSETS SHOULD BE BETWEEN 700 AND 1300 AT IDLE

Example of a Discovery 3 operating within 2 faulty injectors.

Caution:

Land Rover cylinder identification can be confusing. Some tools do not provide cylinder numbers and some injectors are numbered 0 to 5 with 0 being injector 1!

Refer to vehicle specific diagnostic information.

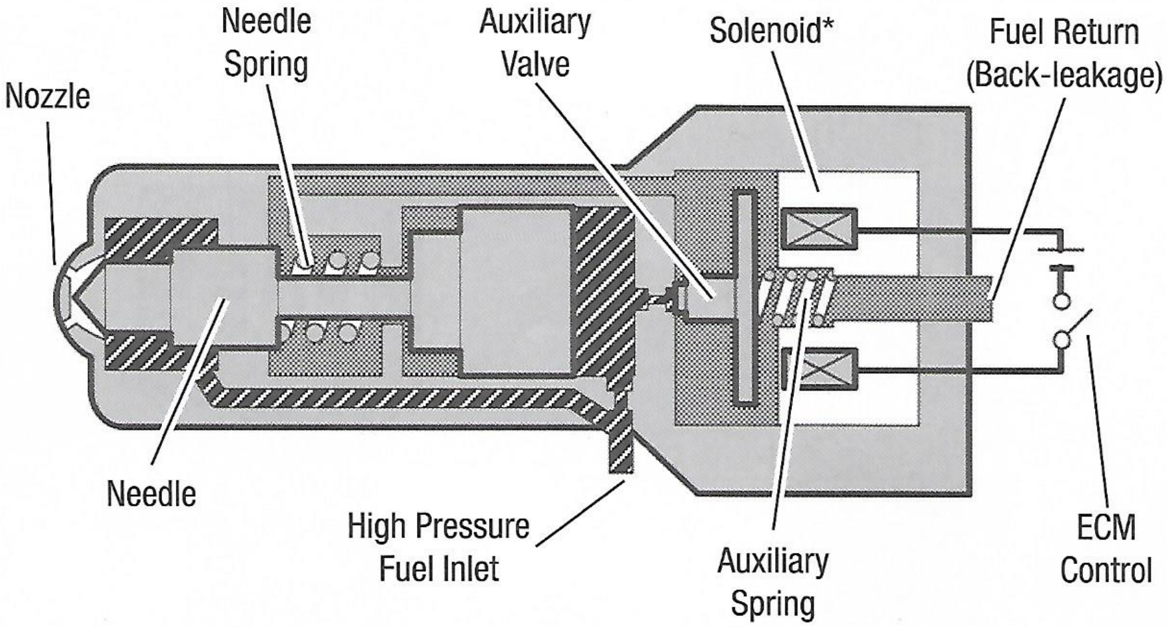


INJECTOR BACK-LEAKAGE TEST

The Injector Back-leakage Test measures the amount of fuel used to actuate each individual injector. This is a useful tool in diagnosing if any cylinder imbalance is caused by the control circuit of an injector or its nozzle.

As a general rule; nozzle faults can be addressed with an off vehicle injector clean and/or service. Control fault on CRD injectors usually require the fitment of a new injector.

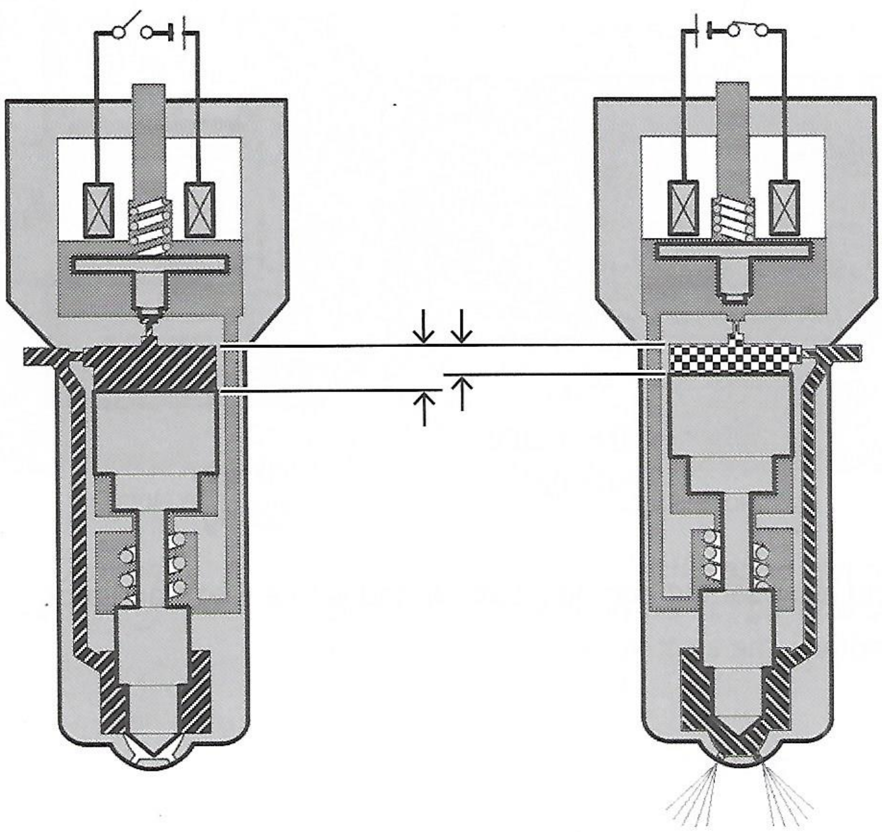
Parts of a CRD Injector:


Nozzle
Needle Spring
Auxiliary Valve
Solenoid*
Fuel Return (Back-leakage)
Needle
High Pressure Fuel Inlet
Auxiliary Spring
ECM Control

* The solenoid represented can be interchanged with a Piezo actuator.

INJECTOR BACK-LEAKAGE TEST continued...

The creation of Back-leakage:
Back-leakage is quite simply the displacement created from the actuation of the needle.
As a general rule; the quantity is irrelevant. What is important is that all cylinders are balanced. It is generally accepted that a good result is anything under a 10% variation, but this is very general and many back-leakage test kits don't put values on the increments intentionally.
If there is a failure in the auxiliary control circuit of a CRD injector there will be a significant difference between the back-leakage quantities.
The following diagram represents the difference between a closed and an open injector.



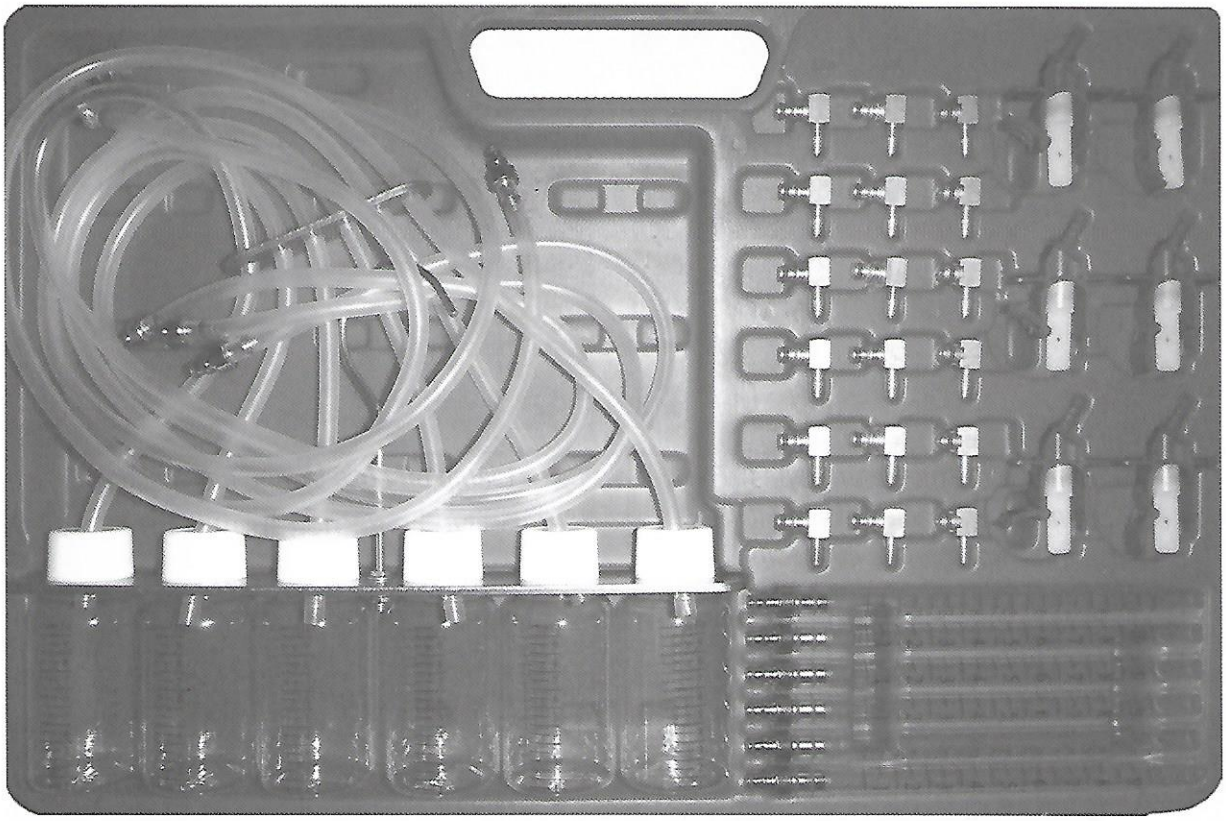
INJECTOR BACK-LEAKAGE TEST continued...

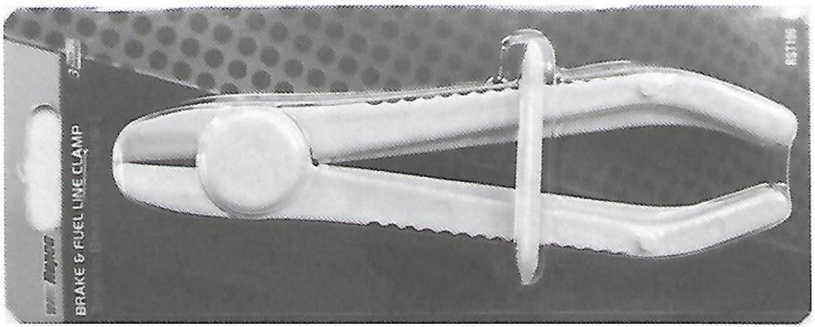
Back-leakage Test Kit

The Back-leakage Test Kit requires the following components:

- Collection Vials with hoses (one per cylinder)
- Selection of injector couplings to suit injector manufacturer
- Selection of blanking plugs and/or pipe clamp*

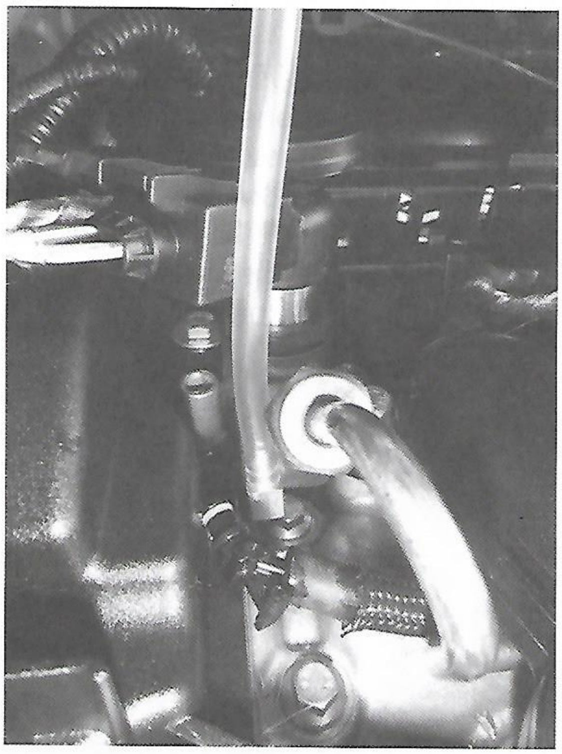
* The injector return pipes usually 'T' into the same return line as the HPFP. This means that you will need to either blank off the disconnected lines or if soft hose pipes are used they can often be closed off with a pipe clamp.



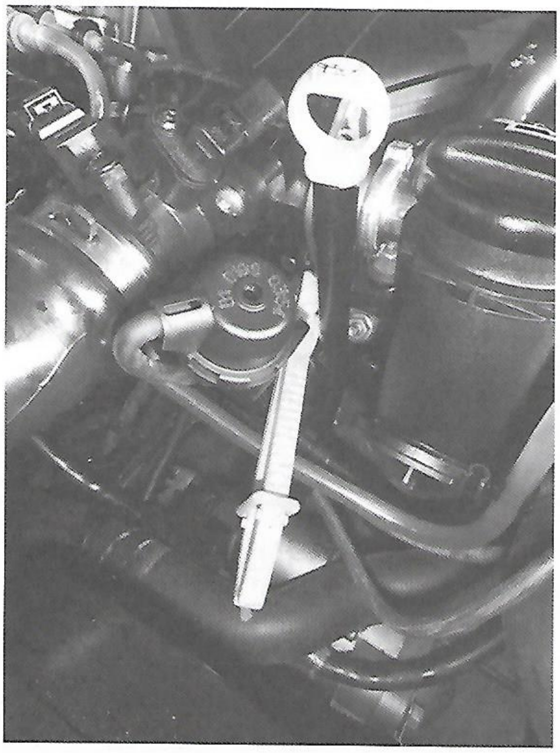


INJECTOR BACK-LEAKAGE TEST continued...

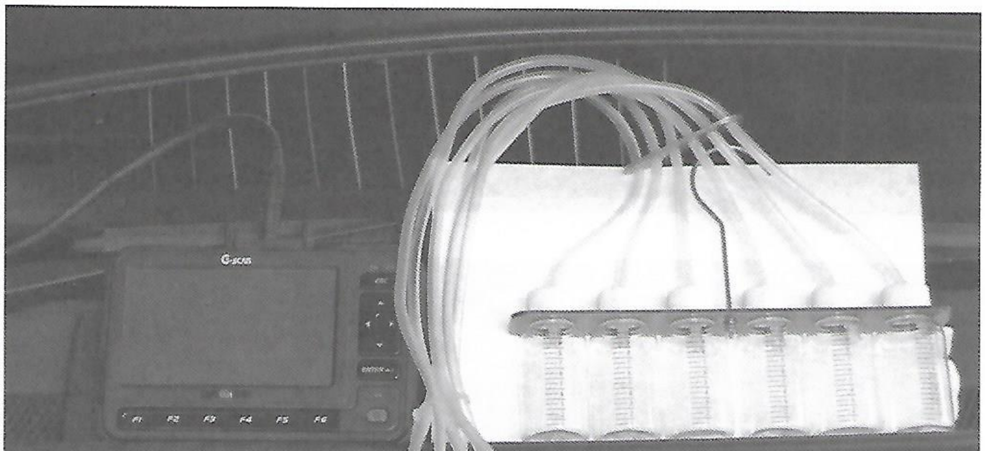
Connecting the Back-leakage Test Kit



Remove the fuel return pipes
Connect the back leakage kit
using the appropriate connectors.



Clamp off hose to stop fuel leakage.

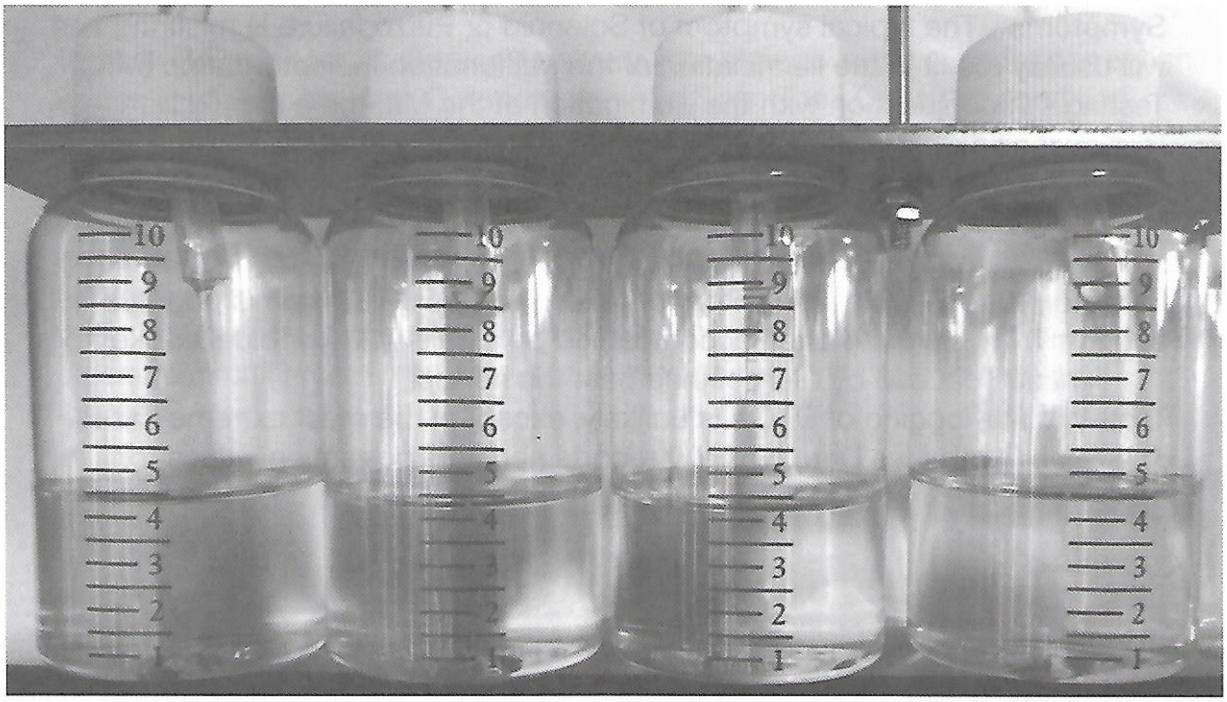


Place/hang the vials from an appropriate position.

INJECTOR BACK-LEAKAGE TEST continued...

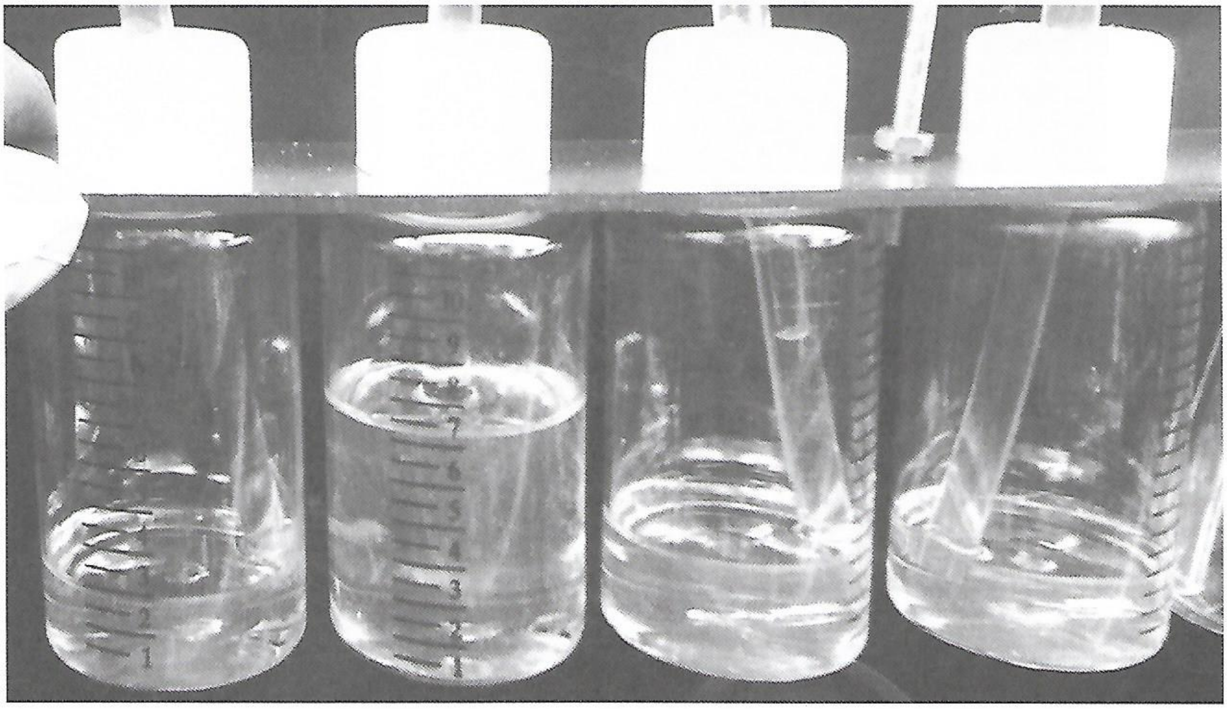
Back-leakage Test Results:

The image of the test results says it all,



A very even output across all cylinders.

Note: *The image below is an example of a typical poor result. One sometimes two injectors with a vastly different result!*



TYPICAL CRD INJECTOR FAILURE POINTS

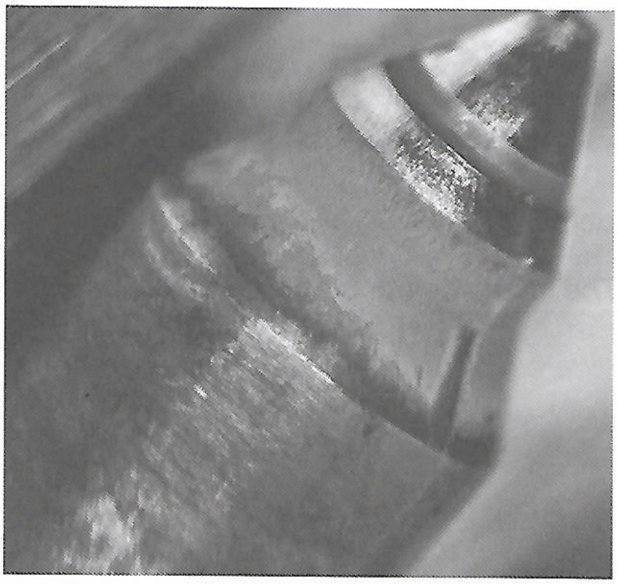
The following paragraph highlights three of the most common types of CRD Injector failure.

Solenoid or Piezo Failure:

Symptoms - The typical symptom of Solenoid or Piezo failure is misfiring and will usually result in the illumination of the Malfunction Indicator Lamp (MIL).
Testing - In conjunction with the illumination of the MIL there should be Diagnostic Trouble Codes (DTC's) logged accordingly. A Back-leakage Test will result in no fuel being returned.

Nozzle or Needle Erosion

Symptoms - The typical symptom of Nozzle or Needle Erosion is poor fuel economy. This is quite often accompanied by a pale white or blue smoke from the exhaust, caused by fuel seeping past the nozzle.
Testing - The logging of DTC's is unlikely, except in the most extreme cases. The Scan Tool's Live Data typically reports negative correction values for affected cylinders and the Back-leakage Test will be normal.



Example of Needle Erosion

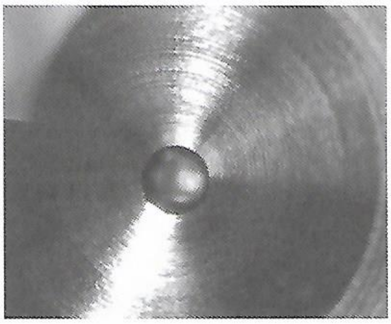
Actual Size

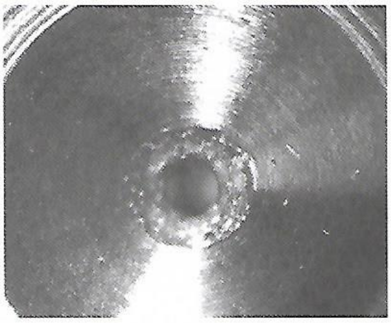
TYPICAL CRD INJECTOR FAILURE POINTS continued...

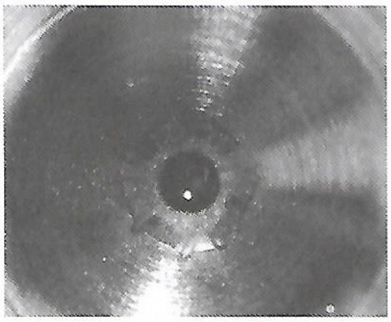
Auxiliary Valve, Ball or Seat Erosion:

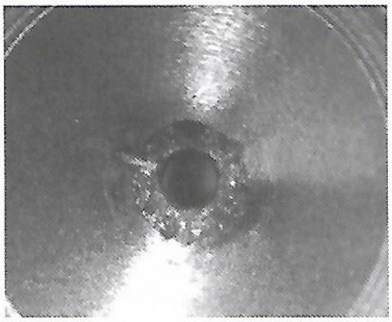
Symptoms - Typical symptoms for Auxiliary Valve, Ball or Seat Erosion is hard starting and performance issues. More severe cases may progress into rough running (cylinder imbalance) due to the injector remaining open or partially open.

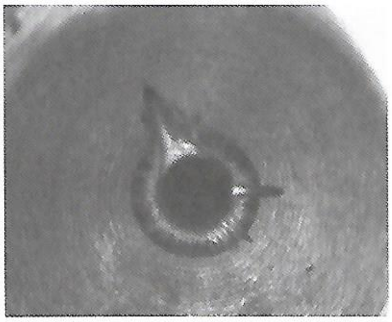
Testing - In most cases there will be very little change in the cylinder correction values read from the Live Data function of a Scan Tool. Once the condition reaches the stage where the injector no longer closes properly, it would be expected that the faulty cylinder/s would display negative correction values for obvious reasons. This fault is easily detected in its early stages with a Back-leakage test. High pressure fuel escapes past the Auxiliary Valve and into the return system, during the Back-leakage test. This is collected and compared. With virtually zero pressure in the return circuit and up to 200,000kPa in the high pressure circuit, very small amounts of erosion result in big differences in Back-leakage.


New seat


Erosion example #1


Erosion example #2


Erosion example #3


Erosion example #4

Actual size

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